

# Energy Management & Conservation Manual



وزارة المياه والري



*Academy for Educational Development*  
أكاديمية التطوير التربوي (واشنطن)



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One of the main difficulties Jordan faces is lack of natural resources, among which is energy. Therefore the high cost of energy became an uncontrollable factor which creates the need to investigate opportunities to fully utilize energy and minimize wastages and save money.

### **Jordan Energy Consumption Figures**

According to the Ministry of Energy and Mineral Resources (MEMR) and a study conducted by EMS in 1998, the average energy consumption per capita in 1997 was 1016-kg oil equivalent (KgOE) compared with 1033-kg oil equivalent in 1996.

The cost of imported crude oil and petroleum in 1997 was JD 367 million with a 6.4% increase from the pervious year. This cost contributes to 34% of Jordan's exports and 12.6% of imports. Over the last decade, the cost of imported oil ranged from 6% to 12% of the gross domestic product (GDP) and 32% to 129% of the value exported goods.

This clearly shows that the cost of imported energy had surpassed the Kingdom's revenue from exports for some years. It is estimated that the national rates of energy and electricity consumption in 2110 will be approximately 7 million Tons Oil Equivalent (TOE). Estimates places future energy cost at USD 800 million, which will constitute 13% of the gross national income; this is a high percentage when compared with the 4% typical for industrial countries.

The electricity generation sector ranked first in energy consumption, which consumes 35% of the total primary energy, i.e. 1636 TOE in 1997, which represents an annual growth of 3.7% against 7% in 1996.

The following table (1) shows the Kingdom energy balance for the year 1997, from which it is clear that the transportation sector represents the major final energy consumer, at 40.2% of the total energy followed by the industrial sector

**Table (1)**

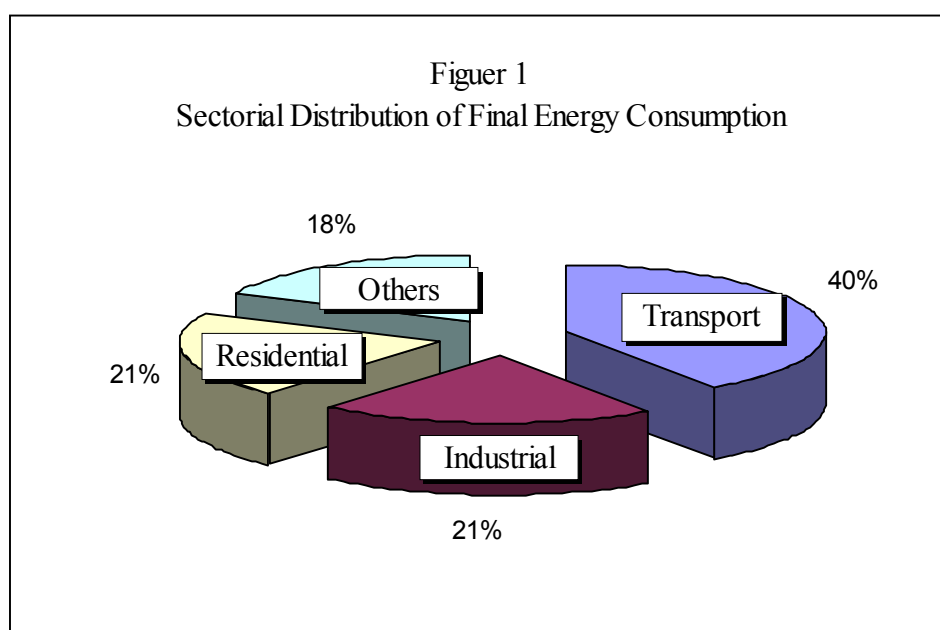
1997 Energy Balance 1000 TOE						
	Industrial	Transport	Residential	Services	Others	Total
Heavy Fuel Oil (HVO)	391	4.3	0	0	0	395.3
Diesel	150	543	49	112	153.4	1007.4
Gasoline	0	554.4	0	0	0	554.4
LPG	2.8	0	250	16.5	7	276.3
Kerosene	2	0	201.3	11	0	214.3
Aviation Fuel	0	233.2	0	0	0	233.2
Other	0	0	0	0	123	123
Electricity	154.7	0	140	51.9	107.6	454.2
Solar Energy	0	0	54	0	6	60
Total	700.5	1334.9	694.3	191.4	397	3318.1

The following table (2) represents the sectorial distribution of the final energy Consumption in Jordan from 1994 through 1997. The table indicates a slight increase in the final energy consumption averaging at 2.8 % per year.

**Table (2)**

<i>Sectorial Distribution of Final Energy Consumption</i> (10 <sup>3</sup> ) TOE				
<b>Sector</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>
<b>Transportation</b>	<b>1157</b>	<b>1254</b>	<b>1305</b>	<b>1335</b>
<b>Industrial</b>	<b>664</b>	<b>686</b>	<b>652</b>	<b>700</b>
<b>Residential</b>	<b>566</b>	<b>568</b>	<b>632</b>	<b>694</b>
<b>Others</b>	<b>598</b>	<b>630</b>	<b>581</b>	<b>588</b>
<b>Total</b>	<b>2985</b>	<b>3138</b>	<b>3170</b>	<b>3318</b>

The following figure (1) represents the percentages of final energy consumption for the different sectors of energy consumers.

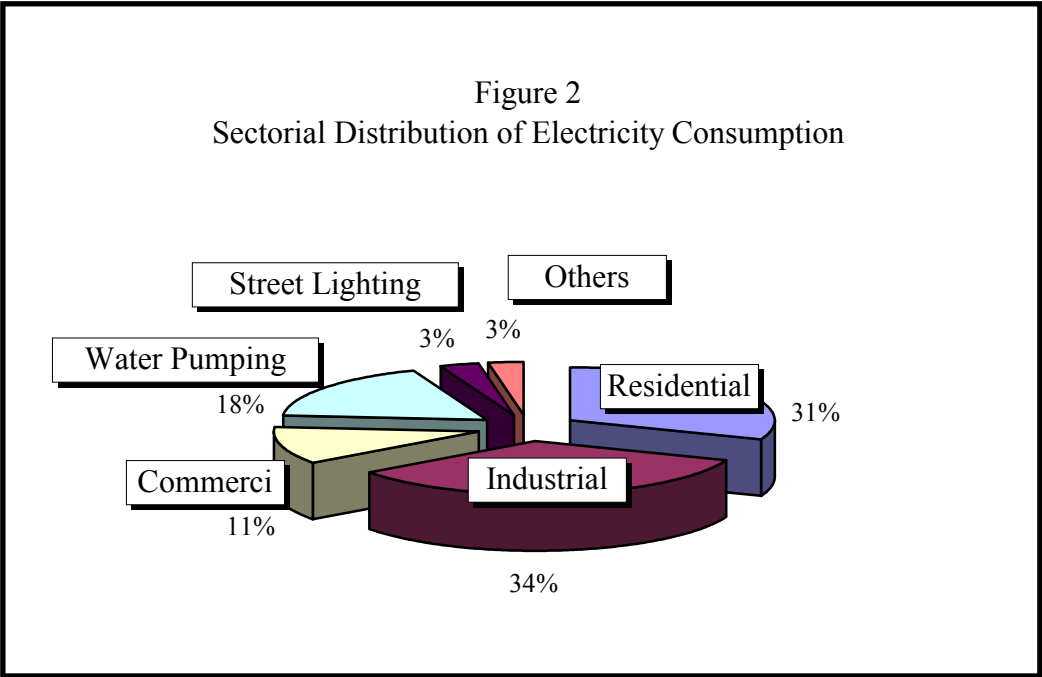


The industrial sector, as table (3) shows, is the largest consumer of electricity in Jordan in 1997. It consumed about 34.1% of the total consumption followed by the Residential sector. The following table (3) represents the sectorial distribution of electricity consumption in Jordan for the past four years.

**Table (3)**

<b>Sectorial Distribution of Electricity Consumption in Jordan</b>				
<b>Sector</b>	<b>1994</b>	<b>1995</b>	<b>1996</b>	<b>1997</b>
<b>Residential</b>	<b>1317</b>	<b>1411</b>	<b>1562</b>	<b>1628</b>
<b>Industrial</b>	<b>1519</b>	<b>1669</b>	<b>1773</b>	<b>1799</b>
<b>Commercial</b>	<b>476</b>	<b>512</b>	<b>578</b>	<b>603</b>
<b>Water Pumping</b>	<b>768</b>	<b>916</b>	<b>921</b>	<b>936</b>
<b>Street Lighting</b>	<b>114</b>	<b>131</b>	<b>160</b>	<b>174</b>
<b>Others</b>	<b>136</b>	<b>146</b>	<b>128</b>	<b>141</b>
<b>Total</b>	<b>4330</b>	<b>4785</b>	<b>5122</b>	<b>5281</b>

The following figure (2) represents the sectorial distribution of electricity consumption



## **Your Home Energy Use**

The first step to taking a whole-house energy efficiency approach is to find out which parts of your house use the most energy. You can conduct a simple home energy audit yourself.

### **Formulating Your Plan**

After you have identified places where your home is losing energy, assign priorities to your energy needs by asking yourself a few important questions:

1. How much money do you spend on energy?
2. Where are your greatest energy losses?
3. How long will it take for an investment in energy efficiency to pay for itself in energy savings?
4. Can you do the job yourself, or will you need to hire a contractor?
5. What is your budget and how much time do you have to spend on maintenance and repair?

Once you assign priorities to your energy needs, you can form a whole-house efficiency plan. Your plan will provide you with a strategy for making smart purchases and home improvements that maximize energy efficiency and save the most money.

## **Heating and Cooling**

Heating and cooling your home uses more energy and drains more energy than any other system in your home. Typically, 44% of your utility bill goes to heating and cooling.

No matter what kind of heating, and air-conditioning system you have in your house, you can save money and increase comfort by properly maintaining and upgrading your equipment. But remember, an energy-efficient boiler alone will not have as great an impact on your energy bills as using the whole-house approach. By combining

proper equipment maintenance and upgrades with appropriate insulation, and thermostat settings, you can cut your energy bills in half.

## **Landscaping**

Landscaping is a natural and beautiful way to keep your home more comfortable and reduce your energy bills. In addition to adding aesthetic value and environmental quality to your home, a well-placed tree, shrub, or vine can deliver effective shade, act as a windbreak, and reduce overall energy bills.

Carefully positioned trees can save up to 25% of a typical household's energy for heating and cooling. During the summer months, the most effective way to keep your home cool is to prevent the heat from building up in the first place. A primary source of heat buildup is sunlight absorbed by your home's roof, walls, and windows. Dark colored home exteriors absorb 70% to 90% of the radiant energy from the sun that strikes the home's surfaces. Some of this absorbed energy is then transferred into your home by way of conduction, resulting in heat gain inside the house.

Landscaping can also help block and absorb the sun's energy to help decrease heat buildup in your home by providing shade and evaporative cooling.

Shading and evaporative cooling from trees can reduce the air temperature around your home.

Orientation of the house and surrounding landscaping has a large effect on energy consumption. A well-oriented, well-designed home admits low-angle winter sun to reduce heating bills; rejects overhead summer sun to reduce cooling bills; and minimizes the chill effect of winter winds. Fences, walls, other nearby buildings, and rows of trees or shrubs block or channel the wind.. Trees provide shade, windbreaks, and wind channels. Pavement reflects or absorbs heat, depending on whether it is light or dark in color.

## **Lighting**

Increasing your lighting efficiency is one of the fastest ways to decrease your energy bills. If you replace 25% of your lights in high-use areas with fluorescents, you can save about 50% of your lighting energy bill.

### **a. Indoor Lighting**

Use linear fluorescent and energy-efficient compact fluorescent lamps (CFLs) in fixtures throughout your home to provide high-quality and high-efficiency lighting. Fluorescent lamps are much more efficient than incandescent bulbs and last 6 to 10 times longer. Although fluorescent and compact fluorescent lamps are more expensive than incandescent bulbs, they pay for themselves by saving energy over their lifetime.

### **b. Outdoor Lighting**

Many homeowners use outdoor lighting for decoration and security. When shopping for outdoor lights, you will find a variety of products, from low-voltage pathway lighting to high-sodium motion-detector floodlights. A great way for saving is to use Solar lighting which uses energy from sun.

## **Water Heating**

Water heating is the third largest energy expense in your home. It typically accounts for about 14% of your utility bill.

### **There are five ways to cut your water heating bills:**

1. Use less hot water by using Water Saving Devices.
2. Turn down the set point of the boiler thermostat.
3. Insulate your water tanks and pipes.
4. Use solar energy

A family of four, each showering for 5 minutes a day, uses 2.5 m<sup>3</sup> of water a week; this is enough for more than a year supply of drinking water for one person. You can cut that amount in half simply by using low-flow showerheads which gives a max.

Flow rate of 9 liter/min and aerators for faucets, which gives a max. flow rate of 6 liters/min.

## **Appliances**

Appliances account for about 20% of your household's energy consumption, with refrigerators and clothes dryers at the top of the consumption list.

When you are shopping for appliances, you can think of two price tags. The first one covers the purchase price, think of it as a down payment. The second price tag is the cost of operating the appliance during its lifetime. You will be paying on that second price tag every month with your utility bill for the next 10 to 20 years, depending on the appliances. Refrigerators last an average of 20 years; room air conditioners and dishwashers, about 10 years each; clothes washers, about 14 years.

**In Jordan the most common difficulties related to energy are:**

1. Quality of Power: One of the main problems is the high harmonics that may cause damages to equipment and machines and leads to delays and downtime in the industrial factories.
2. No use of Solar energy : Although Jordan is known to have too much sun as sun shines most of the year (nearly 300 days in Amman area for example) but still the utilization of solar energy remains limited to households application. Therefore introducing equipments that would facilitate the usage of the solar energy such as solar panels and cells and spreading the awareness among the public about means of using the solar energy in households and industrial application will lead to significant reduction in energy consumption.
3. No regular calibration and cleaning for boilers: This is a common problem for both households and commercial and industrial premises. Cleaning and calibrating boilers on regular basis leads to increasing the operational efficiency as well as reducing fuel consumption.
4. Water leakage is found in houses, streets and factories especially the food sector. Landscapping and irrigation of private and commercial farms use great amounts of water too.
5. Control of equipment and lighting: Control of equipment depends on a high extent on human factor which is not that reliable . This causes machines and equipment to be left working although not in use and lighting left on in unoccupied areas.
6. Another common thing is buying used spare parts, equipment, and production machines. Almost 90% of these cases consider initial cost and running costs and loads are not foreseen, which results in obsolete items with low operation efficiency and very high energy consumption. .
7. Lack of awareness among the population in general and workers specially in energy related aspects. Real understanding of terms such as tariffs and peak

is absent and even energy efficient features available in the equipment are not used. This leads that the managements become hesitant to bring high technology automated lines fearing not to find reliable workers.

8. A lot of factories in Jordan work on corrective maintenance rather than on preventive maintenance. This usually leads to increase in the energy consumption as well as damages to the equipment itself.

Both oil and electricity , considered as the most popular sources of energy are very expensive in Jordan. Jordan is not producing oil like other countries in the area.

However , Jordan has the advantage of free liquid gas supply from Iraq, but there is not a proper infrastructure for the utilization of this gas. For the time being, it is only used in a bottle form mainly to supply stoves and heaters. The cost of conventional sources of energy is given in table (4) below:

**Table (4)**

<b>JORDAN Electrical Tariff</b>			
<b>Consumer</b>	<b>Classification</b>	<b>Tariff type</b>	<b>Effective Final Electrical Tariff ( JD/kWh or JD )</b>
			New 16/6/2002
Domestic Consumers	Standard	1-160 kWh/Month	0.034
		161-300 kWh/Month	0.058
		301-500 kWh/Month	0.067
		>500 kWh/Month	0.083
Broadcasting & TV	---	Flat	0.063
Commercial Consumers	Commercial	Flat	0.065
Industrial Consumers	Small	Flat	0.041
	Medium	Max. Demand	3.05
		Day	0.038
		Night	0.028
Agricultural Consumers	Agricultural	Flat	0.029
Water Pumping	---	Flat	0.041
Hotels	Hotels	Flat	0.063
Street Lighting	---	Flat > Year1988	0.028
JEPCO & IDECO	Bulk	Max. Demand	2.4
		Day	0.0344
		Night	0.0244
Large Consumers	Bulk	Max. Demand	2.4
		Day	0.051
		Night	0.0365
<b>JORDAN Fuel Prices</b>			
<b>Fuel Type</b>	<b>Price</b>		
	<b>Refinery</b>	<b>Distributor</b>	
Kerosene	0.09 ( JD/Liter )	0.091 ( JD/Liter )	
Diesel	0.105 ( JD/Liter )	0.106 ( JD/Liter )	
Heavy Fuel Oil	72 (JD/Ton)	---	
LPG	---	2 ( JD/12.5 Kg Cylinder)	

## Heating and Hot Water

### 1. What are the different types of boilers available in Jordan? Advantages and disadvantages of each?

- a) Steam Boilers, for industrial applications, it produces steam.
- b) Oil Boilers, for drying purposes in industrial applications.
- c) Hot Air Boiler, for industrial applications, it produces hot air.
- d) Diesel / hot water Boiler used for both industrial and residential applications for both heating and hot water supply

For residential and domestic use in industries the diesel (hot water) boiler is the most common, these kind of boilers exist in two forms; Cast Iron, where all its internal parts are made from cast iron and the second is the Steel type, where steel metal sheets make all its internal parts.

The Steel boilers are less expensive but when it comes to efficiency, cast iron keeps the heat for longer periods thus making it more efficient.

Efficiency	Price
Cast Iron	Steel
Steel	Cast Iron

### 2. What can electric heaters or solar systems used for? Can they replace boilers? What are their advantages and disadvantages?

Both systems are used for hot water supply but none of these systems can replace a diesel boiler system since they can't be used for heating.

#### Electric Heaters

Advantages	Disadvantages
Fast Practical for offices	High Running cost (Using fuel source (diesel) is cheaper 60% less than electricity)

Solar heaters

Advantages	Disadvantages
No running cost	Not fully utilized in winter
Environment friendly	Low water temperature
	Limited Storage Capacity
	Can be destroyed when water is scarce and in very cold areas

One of the recommended approaches that will fit here in Jordan is to combine systems; use the solar in summer for hot water since no heating is required. The diesel boiler can be used for both heating and hot water in fall and winter .

*Tip : You can use the solar system in the winter for partially heating the water going to the boiler.*

**3. How can we determine the boiler types and sizes that we need at home, does it depend on the number of rooms ? number of occupants?**

Well, the size of the boiler doesn't depend on the occupants number or number of rooms but on the area and the wall construction of the house, the ambient temperature for apartments, is there any floors above..etc. Special equations are used for that purpose that cannot be stated here , but a good practice is to consult more than one supplier when buying a new boiler.

**4. How will I recognize if a part my plumber brings is new or recycled?**

Usually , and since in these systems there's a contact with diesel, used parts can be described as stained and dark in color. To avoid being cheated on, you can buy the parts yourself or accompany the plumber when buying this part.

**5. What is the energy efficient pattern for operating the boiler in winter?**

A study conducted by EMS showed that if you're operating your boiler in less than or equal to 12 hours per day, its recommended that you put it on for longer periods and for fewer times. i.e. operating it twice for 3 hours is better than

operating it 3 times, two hours each. If you operate your boiler for more than 12 hours a day, it would be better not to turn it off at all and keep it running as this will be the best operating conditions in terms of efficiency and cost.

**6. What are the different types of radiators (convectors) available in Jordan? Advantages and disadvantages of each? How do we determine the required sizes and numbers?**

There are two different kinds, Cast iron and steel convectors, although the steel panels are significantly less expensive the cast iron is more efficient. Determining The size and numbers of panels per room is a design issue that depends on the room area, insulation, windows and again wall structure of the building.

**Efficiency**

☛☛ Cast Iron radiators

☛ Steel Convectors

**Cost**

☛☛ Steel Convectors

☛ Cast Iron radiators

**7. What good practices can be done to increase the efficiency of the heating and hot water systems?**

- ☺ Insulation of walls, pipes and tanks
- ☺ Double Glaze for windows
- ☺ Sheltering, planting trees especially in the western side of the house and in front of windows.
- ☺ Repairing cracks around windows.
- ☺ Keep furniture and décor away from radiators.
- ☺ Boiler Cleaning and Calibration, once or twice yearly.
- ☺ Turning down the set point of the boiler's thermostat for hot water to **60-70 ° C.**

According to a study conducted by European Solar Industry Federation (ESIF) in 1994 on the solar thermal market in Jordan, more than 150 000 units of Domestic solar water heaters have been installed in Jordan that time. The Estimated annual solar thermal energy production was 225.000 MWh/year, and reductions in the CO2 emissions in one year were 191.000 tons/year.

By the 90s, the number of houses utilizing solar water heaters was estimated to be 158.669 (more than 20% of total houses in Jordan). Almost 100% of the systems sold have been installed in houses. The installation of solar systems is avoided in big hotels and public buildings because the systems locally produced have quality problems and a very limited life time. The great majority of solar water heaters are Domestic Hot Water systems manufactured locally.

Some of the manufacturers of solar thermal systems in Jordan are:

1. Rum founded in 1990 , the biggest manufacturers in Jordan .
2. Specialized Engineering Industries Co.
3. Shahrouri Manufacturing Company started in 1982
4. Arab Industries For Solar Machinery & Equipment Co. (Hanania)

\* Recommendation : An energy conservation law that will mandate that all new buildings should have solar panels from now on as per the construction codes. This will save a good percentage from the energy that is required for space heating and hot water supply in Jordan which is about 12% of the total energy consumed according to the Ministry of Energy and Natural Resources.

## **Air Conditioning System**

### **1. What are available Air Conditioning Systems in Jordan. How can we determine our requirements?**

Air Conditioning systems available in Jordan are:

#### **a. For residential and small offices :**

1. Split Units Cooling Systems
2. Windows Units (usually but not necessarily installed on windows).
3. Package Units

#### **b. For Commercial and Industrial Applications:**

1. Chillers with Air Handling Units : Used for Cooling very big areas.
2. Chillers with Fan coil Units : For small separate areas.

The following table shows their ranking according to price, noise level and ease of control.

Price	Noise Level	Control
Window	Split	Window
Split	Package	Split
Package	Window	Package

As we can see the window type is the best when price and control are considered but its noise level is very high so its not recommended in houses

Package units are recommended for big areas , offices and villas (such as guest rooms) as the number of units required will be less than if buying split units type. For rooms and apartments, split units is the best choice for control purposes.

Choosing size and the type of AC systems is a design issue that depends on many factors, such as the wall and glass area and the number of occupants and appliances and equipment in that specific area, the wall construction of the house, the ambient temperature for the apartments, if there is any additional floors above ..etc. Special equations are used for that purpose that cannot be stated here but a good practice is to consult more than one supplier.

## **2. Is it recommended to install combined heating and cooling systems?**

For unheated offices and houses buying a heat pump for air conditioning and heating is a good option , but for houses that already have diesel boilers its recommended to use the boiler for heating as the cost of fuel is 60% less expensive than electricity in Jordan.

## **3. Does the selection of systems vary in different areas in Jordan?**

Choosing the heating and cooling systems and determining its size vary with the ambient temperature in Amman, Aqaba, Irbid and rural areas.

## **Water Pumps**

### **4. What are the different water pumps needed in an average house? How can we determine the size of each water pump ?**

***Water pumps exist in three types in houses in Jordan:***

1. Domestic hot water pump: pumps hot water from the boiler to different water outlets in the house, its size depends mostly on the required flow, number of outlets and the distance between outlets and the boiler.
2. Well water pump: pumps water from the well to the tanks , its selection depends on the flow requirement and the distance.
3. Tank pump: pumps cold water from tanks to different application and depends mainly on the flow requirement ( pressure).

**How different cost effective and feasible control means can be used to increase the efficiency and reduce the energy used by pumps?**

1. For Domestic hot water pumps , timers can be used to operate the boiler.
2. Well water pumps can be controlled using level switch control as the pump operates when level of water becomes lower than a certain level.
3. Tank pumps can be controlled by pressure controls, if the pressure drops due to using an outlet, the control operate the pump.

## **Section III**

### *Lighting System*

## **Topics that will be covered in this session**

- ◆ Lighting Survey.
- ◆ Families of Lamps.
- ◆ Energy Savings Opportunities.
  1. Turning off excess lighting.
  2. Lamp substitution.
  3. Energy efficient reflectors.
  4. Electronic Ballasts.
  5. Programmable timers.
  6. Time delay timers.
  7. Occupancy Detectors & Photo cell.

## **Tips**

- ❖ Lighting consumes about 4% of the world Energy Consumption.
- ❖ Lighting Consumption is major in Commercial Sector.
- ❖ Always paint the walls with light colors.
- ❖ Always study the economical feasibility of any suggested energy saving measure.
- ❖ Don't forget to include the labor cost and accessories in the investment.

## BACKGROUND

- *Lighting Consumes about 4 % of The World Energy Consumption.*
- *Different Types With Different Performance & Energy C/S's Exist.*
- *Lighting Consumption is Major in Commercial Sector, Less in Industrial Sector*

### Building or Entity Analysis

- **Recommended Procedure:**
  1. Conduct a Survey, or:
  2. Review Project Plans
    - Less Satisfactory.
    - Do Random Check.

### Lighting Survey

It is needed to collect the following information:

- Seeing Tasks & Their Location.
- Type & Quantity of Existing System.
- Present Lighting Levels.
- Lighting Control / Space.
- Reflectance of Walls, Ceiling & Floor.
- Space Geometry (Area Dimensions).
- Operating Schedules.

Please refer to the lighting survey form at the appendix.

### Evaluation

1. Evaluation of Individual Spaces.

Evaluate each space alone, not the whole building.

2. Study Possible Improvements:

- Consider Different Options.
- Choose Most Economical & Practical option.

Two Choices to be made in making changes in a Lighting System:

1. **Modification of Existing System.**

- Simplest Way.
- Examples:
  - Replacing Lamps.
  - Change Switching Circuits.

## 2. Replacement with Another System

- Requires Higher Investment.
- Should Be Economically Justified.
- **Example:**
  - 1000W Mercury Lamp gives 44700 Lumens.
  - Replace it with 400W High Pressure Sodium that gives 45000 Lumens.
  - Savings = 605 W Per Fixture.
  - Same Light Level is maintained.
  - Annual Savings = JD 223
  - Investment = JD 267
  - P/B Period = 14 Months
  - Result: Proposal is justified.

### Priorities

The following should be taken into consideration :

- Initial Cost.
- Client Needs & Requirements.
- Applicability.
- Feasibility.
- Timing.

### Initial Cost VS. Annual Operating Cost

Initial Costs Include:

- Lamps or Fixtures.
- Wiring.
- Installation.

Annual Costs Include:

- Failure Lamp Replacement.
- Maintenance.
- Electricity (Energy).

### Task Lighting Objective

To Provide:

- Task Related Illumination.
- Avoid Unnecessarily High Levels of Uniform Lighting Throughout the Space.

### Lighting Levels

The recommended illuminance levels could be obtained from:

1. IES Lighting Handbook ( USA ).
2. CIBSE Code ( UK ).

At the design stage consider both:

1. Quantity of Light
2. Quality of Light

### **Illuminance Modifications**

1. Lower Luminaires Closer To Work Surface:

- Use Lower Wattage Lamps.

2. Relocation of Luminaires:

- Remove Unnecessary Luminaires.

### **Non Illuminance Modifications**

Does Not Involve Lamps, Luminaires, or Other System Components.

- Examples:
  - Group Similar Tasks in One Area.
  - Group Workers Having Similar Operating Schedule in One Area.

### **Reflectance**

- Reflectance of Walls, Ceilings, and Floor Affect The Illumination Levels.
- Light Colors Have Higher Reflectance.
- Avoid Excessively Bright Surfaces.
- As a Guide, IES Recommends:
  - For Office-Type Spaces :
    - Ceiling : 80 - 90 %.
    - Walls : 40 - 60 %.
    - Floors : 20 - 40 %.

### **Space Geometry**

Space Dimensions affect the Distribution of Light in The Area.

- Length.
- Width.
- Height.
- Open Areas are More Efficient.
- Introduction of Partitions Reduce Illumination.
- Large Rooms Utilize Lighting Energy Better Than Do Small Rooms.
- High Ceiling are Less Efficient.

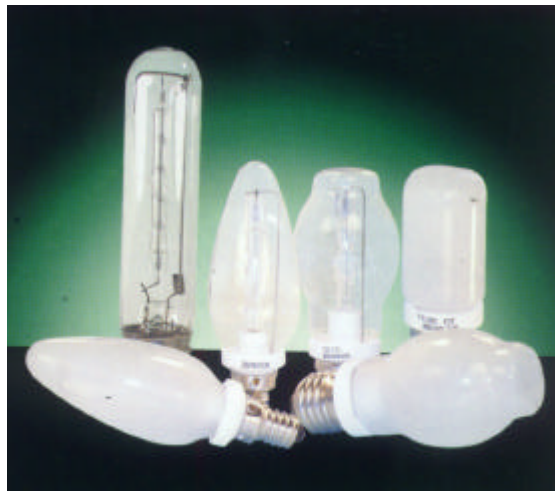
## Families Of Lamps

1. Incandescent & Tungsten Halogen.
2. Fluorescent.
3. High Intensity Discharge Lamps.
  - A. Mercury Vapor Lamps.
  - B. Metal Halide Lamps.
  - C. High Pressure Sodium Lamps.
  - D. Low Pressure Sodium Lamps.

### Incandescent & Tungsten Halogen



Incandescent Lamp



Halogen Lamps

- Produces Light By Electrical Heating of a Wire (Filament) till Radiation.
- Filled with Inert Gas (N, AR).
- The Cap:
  - E: Edison (Screw).
  - B: Bayonet.
- Halogen: Filled with Halogen.
- Rating: 15 -2000 Watt.

## Fluorescent Lamps



- Light is Produced By Fluorescent Powders Activated By the Ultraviolet Energy of the Discharge.
- Contains Mercury Vapor at L.P.
- Requires a Ballast & Starter.

## HID - Mercury Vapor Lamps



- Produces Light When Electrical Current Passes Through a Small Amount of Mercury Vapor.
- Consists of Two Glass Envelopes.
- Requires a Ballast to Operate.
- Rating: 50 - 1000 Watt.
- Very Similar in Construction to Mercury Lamps.
- Major Difference:  
Contains Various Metal Halide Additives in Addition to Mercury Vapor.
- Rating: 70 - 3500W.

**HID - High Pressure Sodium**

- Light is Produced When Electrical Current Passes Through a Sodium Vapor.
- Has Two Envelopes:
  - Inner - In Which Light Producing Arc is Struck.
  - Outer - Protective, Clear or Coated.
- Light Color is Golden Yellow.
- Most Efficient of ALL.
- Has a Monochromatic Light Output (Yellow).
- Used Where Color is Not Important.
- Sodium Vapor in Evacuated Envelope Produce The Light.
- Rating: 18 -180 Watt.

**How to Define Lamp Type?**

- By Shape.
- By Light Color.
- By Starting Time.
- By Model No.

Manufacturer	Incandescent	Halogen	Fluorescent	Blended Mercury
Philips	Standard A	500 T3 Q / CL / P	TL ' D36 W / 25	ML 160 W
Osram	H R I M	64702 Halo LINE	L 36 / 25	H W L

Manufacturer	Mercury	Metal Halide	H . P . Sodium	L . P . Sodium
Philips	H P L	H P I - M H D	SON - SDW	S O X
Osram	H Q L	H Q I	N A V	S O X

# Energy Saving In Lighting System

- **Energy ( kWh ) = kW x Hours.**

Energy Can Be Saved By:

- A. Reducing Electrical Load (Power).
- B. Reducing the Operating Time.

## Energy Saving Opportunities

### Group A: Reducing the Power.

- Turning OFF Excess Lighting.
- Lamp Substitution.
- Energy Efficient Reflectors.
- Electronic Ballasts.

### Group B: Reducing the Power.

- Programmable Timers.
- Time Delay Timers.
- Occupancy Detectors & Photocell.

### 1. Turning OFF Excess Lighting:

- Lighting Levels Standards:
  - CIBSE CODE ( UK ).
  - IES Lighting Standards ( USA ).
- Lighting Level is Measured in Lux or Foot Candle Units.
  - 1 FC = 10.76 Lux.

### Identifying The Measure:

- Measure in Different Locations of the Area (Record Notes).
- Compare with Standard Value.
- If Measured > Standard then;
  - There is a Possibility to Remove Units or Lamps.

**Calculations**

$$\text{Measured Lux} = X$$

$$\text{Standard Lux} = Y$$

$$\text{Excess Lamps \%} = (X - Y) / X * 100\%.$$

$$\text{Excess Lamps} = \text{Excess Lamps \%} * \text{Existing number of lamps.}$$

$$\text{Saved Elec. Load ( kW )} = \text{Excess Lamps} * (\text{Lamp Watt.} + \text{Ballast Watt.})$$

$$\text{Saved Elec. Consumption ( kWh )} = \text{Saved Load ( kW )} * \text{Operating Hours.}$$

$$\text{Savings in Energy Cost ( JD )} = \text{Saved Elec. Cons. ( kWh )} * \text{Elec. Tariff ( JD/kWh )}.$$

**Electricity Tariff:**

- Residential: Slides (0.033, 0.055, 0.063, 0.078 JD/kWh)
- Commercial: Flat 0.063 JD/kWh

**Example : Hospital - Laundry Area**

$$\begin{aligned} \text{Excess Lamps \%} &= [(415 - 300) / 415] * 100\% \\ &= 27.7 \%. \end{aligned}$$

$$\text{Excess Lamps ( EL )} = 27.7 \% * 14 = 4 \text{ Lamps ( After Rounding )}$$

$$\begin{aligned} \text{Saved Electrical Load ( kW )} &= \text{No. of Reduced Lamps} * (\text{Lamp kW} + \text{Ballast kW}) \\ &= 4 * (0.036 + 0.010) = 0.184 \text{ kW.} \end{aligned}$$

$$\begin{aligned} \text{Saved Elec. Consumption ( kWh )} &= \text{Saved Elec. Load (Power)} * \text{Operating Hours} \\ &= 0.184 \text{ kW} * 8 \text{ H/D} * 30 \text{ D/M} * 12 \text{ M/Y} \\ &= 530 \text{ kWh / Year} \end{aligned}$$

$$\begin{aligned} \text{Savings (JD)} &= \text{Saved Cons.} * \text{Elec. Tariff.} \\ &= 530 \text{ kWh} * 0.063 \text{ JD/kWh.} \\ &= 33.4 \text{ JD/Year.} \end{aligned}$$

## 2. Lamp Substitution

- A. One-For-One Lamp Substitution.
- B. Family to another Family Substitution.

- Families of Lamps:

- Low Pressure Sodium.
- High Pressure Sodium.
- Metal Halide.
- Fluorescent.
- Mercury.
- Incandescent & Tungsten Halogen.

Highest Efficacy



Highest Efficacy

- $\text{Efficacy} = \text{Lamp Lumens} / \text{Lamp Wattage}.$

### A. One-For-One Lamp Substitution.

- Replace Existing Lamp by a Lower Wattage Lamp.
  - Same Socket.
  - Same Luminaire.
  - Provide Required Illumination.
  - Achieve Required Color C/S's.

**Example:** Replace Inc. 60W Lamp by Energy Efficient Compact Fluorescent 15W.

- Inc. 60W : 730 Lumens, E27 Socket  
220 V, No Ballast.
- C. FL. 15W : 900 Lumens, E27 Socket  
220 V, Built in Ballast.
- 75 % Energy Saving + 23 % Higher Illumination.

**Example:** Replace FL. 40W Lamp by FL. 36W.

- Similar or Higher Lumens.
- Save 10 % of Energy Consumption.
- Replace Old Fluorescent Lamps by New More Efficient Ones.

**B. Family to another Family Substitution.**

- Replace Existing Lamps by another Type which has:
  1. Higher Efficacy
  2. Required or Acceptable C/S's.
- Need to Replace the Whole Unit,  
Or ..
- Only Replace the Lamp & Control Gear.

**Examples:**

- Replace Incandescent Lamps By Fluorescent Lamps Fixtures.
- Replace Tungsten Halogen Fixtures By H. P. Sodium or Metal Halide Units.
- Replace Mercury Units By H. P. Sodium or Metal Halide Units.

**Measurements Required**

1. Lux Measurements.
  - Luxmeter
2. Electrical Load Measurements
  - Digital Multi Meter     Or..
  - Power Demand Analyzer.
3. Operating Hours.

Accurate data can be taken from the lamp or manufacturer catalogues. Operating hours can be taken from area users

**Calculations**

- Similar to Those of Turning OFF Excess Lighting Measure
- Calculate:
  1. Existing System Consumption & Cost
  2. Proposed System Consumption & Cost
  3. Savings = Difference

**Example:** Outdoor Front Wall Lighting

Existing Lamp Type	: Inc. 100W.
No. of Existing Lamps	: 16.
Lighting Operating Time	: 12 Hours/Day.
Proposed Lamps Type	: C. FL. 20W.
• Inc. 100W	: 1380 Lumens.
• C. FL. 20W	: 1200 Lumens.

**Existing Situation:**

Lighting Load	= No. of Lamps x ( Lamp kW x Ballast kW )
	= 16 x 0.100 = 1.6 kW
Elec. Consumption	= Lighting Load x Operating Hours
	= 1.6 kW x 12 H/D x 365 D/Y
	= 7008.0 kWh/Year
Energy Cost	= Elec. Cons. x Electrical Tariff
	= 7008 kWh x 0.063 JD/kWh
	= 441.5 JD/Year

**Proposed Situation :**

Lighting Load	= No. of Lamps x ( Lamp kW x Ballast kW )
	= 16 x 0.020 = 0.32 kW
Elec. Consumption	= Lighting Load x Operating Hours
	= 0.32 kW x 12 H/D x 365 D/Y
	= 1401.6 kWh/Year
Energy Cost	= Elec. Cons. x Electrical Tariff
	= 1401.6 kWh x 0.063 JD/kWh
	= 88.3 JD/Year
Savings	= 441.5 – 88.3
	= 353.2 JD/Year

## Lighting System

### 3. Efficient Reflectors

- Lighting Design Equation

$$N = \frac{E * A}{FL * UL * MF}$$

$$N = \frac{k}{UL}$$

Where,

E : Required Lux.  
 FL : Lamp Lumens.  
 A : Room Area (m2)  
 UF : Utilization Factor.  
 MF : Maintenance Factor.

UF Depends On:

- Luminaire (Reflector).
- Room Colors (Walls, Ceiling)
- Room Index (Length, Width, Height)

$$\text{Room Index} = \frac{L \times W}{(L + W) \times H}$$

#### **Fluorescent Lighting:**

- Sometimes No Reflector Exist then;
  - 50 % of Light is Wasted Upward.
- Normal Reflector Exist then;
  - Part of Light is Absorbed.
  - Part of Light is Wasted Inside the Luminaire.

**Depending on Wall Reflectance & Room Index:**

- If No Reflector Exist then: UF: 0.22 - 0.87.
- If Normal Reflector Exist then: UF: 0.39 - 0.89.
- Using Efficient Reflectors: **UF: 0.80 ~ Approx. 1 Can Be Reached.**
- From Lighting Design Equation:

$$N = \frac{k}{UL}$$

N: Required Number of lighting units to achieve certain Lux.

**Data Required**

In Addition to All Data Collected During Lighting Survey;

- Details about Existing Lighting Fixture.
- Type & Rating.
- Dimensions.
- Manufacturer.

Therefore, Installing energy efficient reflectors will improve the utilization factor (approximately doubled) , and we can remove half at the lamps from fluorescent units without affecting the illumination level.

#### 4. Electronic Ballasts

- Fluorescent Lighting Need a Ballast to Operate.
- Conventional Ballasts are Used.
- Conv. Ballast, Core & Coil, Iron Cored, Magnetic Ballast are Several Names for the Same Devices.

##### **Disadvantages of Conventional Ballasts**

- High Power Loss (10 - 20 %).
- Limited Frequency: Reduces Lamp Efficiency.
- Lower Lamp Lumens Due to Ballast Resistance.
- Need a Starter.
- Heat Sources.
- Affected by Low Temperature.
- Relatively, Heavy Weight:
  - Difficult to Handle.
  - Difficult to Install.
  - Higher Shipping Costs.

##### **Electronic Ballast:**

- Converts 50 Hz Electrical Supply to 25 - 40 kHz, Hence Resulting in Better Performance & C/S's.
- Energy Saving + Better Performance.

##### **Advantages of Electronic Ballasts**

- Much Lower Ballast Losses: Only 1 Watt.
  - FL. 2 x 36W Consumes:

• With Conventional Ballast	: 92 W.
• With Electronic Ballast	: 72 W.
• Savings %	: 22 %.
- Much Smoother Light Output.
- Higher Average Light Output.
- Absence of Audible Noise
- Lower Heat Generation. Reduced Cooling Costs.
- Longer Life (16 - 20 Years)
- Dimming Possibility

- Reduced Weight.
- Longer Lamp Life.
- No Flickering.
- Instant Starting.
- Functioning at Low Temperature (- 10°C).
- No Starter is Required.
- High PF (0.95-1) with no need for capacitors.

**Calculations**

Savings Can Be Estimated Using:

1. Average % of Savings: 20 - 25 % of Total Unit Consumption.
2. Manufacturer Data (Catalogues).
3. Measurements.

# Lighting System

## Need of Lighting Control

Every One Turns On Lighting When He Needs That, But Few People Care to Turn Lighting OFF When They Do Not Need It.

### 5. Control Lighting Using Time Delay Timers (TDT)

Install TDT to:

- Turn On Lighting When Needed.
- Turn OFF Lighting Otherwise.
  
- TDT is a Timed Switch:
  - When Switch is Turned ON.
  - TDT will Turn it OFF After a Pre-Set Time Delay ( Minutes ).
- This Time Delay can Be Adjusted According to Work Requirements.
- Each TDT Has Limited Connected Load ( kW, Ampere,... ).
- Lighting Load to Be Controlled Should Be Within Timer Ratings Or Electromagnetic Contactors Should Be Used to Switch ON/OFF The Load.

### Identifying The Measure

Areas which are Frequently Unoccupied, and Needed Only For Short Periods of Time While Lighting is Operational Regardless of That, Then TDT Can Be Used to Control Lighting Operation.

### Example Cases

- Storing Areas
- Air Compressors Rooms
- Generally, Automatic Machines Rooms
- Lockers Areas
- Staircases

### Calculations

- Similar Approach:
  - Calculate Existing Electrical Consumption.
  - Calculate New Electrical Consumption.
  - Savings = Difference.
  
- Only. Operating Hours Will Change

## 6. Programmable Timers

Potential Areas:

- Areas with considerable number of lighting units (minimum 4 units).
- Areas with windows.
- Areas that are rarely occupied.
- Areas where occupation is for short period for several times.
- Usually closed areas.

### **Types of Programmable Timers:**

1st. Category:

- Electromechanical Timers.
- Electronic Timers.
- Chargeable & Not Chargeable.

2nd Category:

- Daily, Weekly, Monthly, Annually.
- Each Timer Has Limited Connected Load (kW, Ampere).
- Lighting Load to Be Controlled Should Be Within Timer Ratings Or Electromagnetic Contactors Should Be Used to Switch On/OFF The Load.

### **Identifying The Measure**

- Areas Where the Occupation is Continuous or Frequent, But On Pre- Determined Times and Duration, While Lighting is Operational Regardless of That, Then Timers Can Be Used to Control Lighting Operation.
- Areas Where Type of Work May Change During Day Time are Potential Areas For Using Timers to Control Lighting Operation, Part of the Lighting May be Turned OFF, For Example Cleaning Times.

### **Example Cases**

- Offices.
- Production Areas (Break Times).
- Outdoor Decorative Lighting.
- Illuminated Signs.
- Classrooms.

## 7. Occupancy Detectors

Different Names For Same Control:

- Occupancy Detectors or Sensors.
- Motion Detectors.
- Presence or Absence Detectors.
- Occupancy Sensors: Electronic Switch Sensitive to Motion.
  - Switch ON : Detecting a Moving Body.
  - Switch OFF: No Motion.
- Principle of Operation:
  - Passive Infra Red Detectors.
  - Sonic (Sound) Detectors.
- PIR: Detects Invisible Heat Radiation Emitted by Moving Bodies, such as People or Animals.
- Each Detector Has Limited Connected Load (kW, Ampere).
- Lighting Load to Be Controlled Should Be Within Detector Relay Ratings Or Electromagnetic Contactors Should Be Used to Switch On/OFF The Load

### Identifying The Measure

- Areas Where the Occupation is Occasional or Related to a Certain Work That May Not Always Required, While Lighting is always Operational Regardless of That, Then Occupancy Detectors Can Be Used to Control Lighting Operation
- Visual Observations Will Help in Identifying the Measure.
- Asking Proper Questions Will Also Help.
- People Usually Do Not Feel That They Leave Their Offices That Much.

### Example Cases

- Offices Where Occupants Have a Site Activities.
- General Areas That May Be Occupied By Different People.
- Automatic Machines Rooms.
- Storing Areas.
- Meeting Rooms.
- Auditorium.

## Occupancy Sensors Specifications

- Mounting:
  - Wall Mounted.
  - Ceiling Mounted.
- Detection Zone:
  - Wall : Forward, Sides, Angle.
  - Ceiling : Diameter, Height.
- Rated Max. Permissible Load:
  - Measured in Ampere, kW, kVA.
- Switch OFF Delay:
  - Adjustable Time Setting .
- Built in Photocell:
  - Adjustable Light Level Setting.

## Calculations

- Similar Approach:
  1. Existing Electrical Consumption.
  2. New Electrical Consumption.
  3. Savings = Difference.
- Only Operating Hours Will Change.

## Estimating New Operating Hours

1. Can Be Estimated by Determining:

A- Max. No. of Times the Area May Be Used.  
 B- Max. Time Occupied / Time of Use.

New Lighting Operating Time = A x B.

2. Or as a Percentage of Existing Operating Time (25%, 50%, 75%)

## Lighting Controls

- In General: Use any control signal that can minimize the lighting operating hours to reduce lighting energy consumption.
- Same calculations and principles apply for all.

## Example: Hospital: X-Ray Room

### Summary Description:

This room is needed for short periods, several times a day while lighting is always operational.

It is suggested to control lighting using motion detectors

### **Computation Details:**

#### **1. Computation parameters**

Existing No. of Lighting Fixtures	: 6
Existing Lighting Type	: FL. 4x18W
Existing Operating Hours/Day	: 24
Existing Working Days/Month	: 30
Estimated New Oper. Hours/Day	: 50% ( 12 H/D )

#### **2. Annual Energy Saving**

A. Existing situation:

Lighting load	= No. of fixtures * fixture kW
Lamp kW	= 0.018 kW
Ballast kW	= 0.010 kW / 2 Lamps
Fixture kW	= Lamps kW + Ballasts kW = 4 * 0.018 + 2 * 0.010 = 0.092 kW
Lighting Load	= 6 x 0.092  = 0.552 kW
Electrical consumption	= Lighting load * Working hours/year = 0.552 kW * 24 Hrs/day * 30 Days/month * 12 M/Y = 4769.3 kWh/Yr
Lighting consumption cost	= Electrical consumption * electrical tariff = 4769.3 kWh/Yr * 0.063 JD / kWh = 300.5 JD/Yr .

B. Suggested Situation:

No change on the existing lighting load will take place only the operating hours will be reduced from 24 hours to 12 hours daily.

New Electrical Consumption = Lighting load \* operating hours /year.  
 =  $0.552 \text{ kW} * 12 \text{ hr/day} * 30 \text{ day/month} * 12 \text{ month/yr}$   
 = 2384.6 kWh/Yr.

New lighting consumption cost = New consumption \* electrical tariff  
 =  $2384.6 \text{ kWh/Yr} * 0.063 \text{ JD/kWh}$   
 = 150.2 JD/Yr

### 3. Energy Savings:

Saving in electrical consumption = Existing consumption - New consumption  
 =  $4769.3 - 2384.6$   
 = 2384.7 kWh /Year

### 4. Annual Monetary Savings:

Savings in Energy Cost = Existing lighting cost - New lighting cost  
 =  $300.5 - 150.2$   
 = 150.3 JD/Year

Savings = 150 JD / Year

Investment = 125 JD

P/B Period = Investment x 12 / Annual Savings  
 = 10 Months

### Implementation Cost Feasibility

- What we need?
  - Initially:
    1. New Equipment.
    2. Wiring & Accessories.
    3. Installation (Labor).
  - Long Run:
    1. Energy
    2. Maintenance
    3. Complete Replace (End of Lifetime)
1. Equipment Cost: See the suppliers list in the appendix.
  2. Wiring & Accessories:
    - Check site and place of installation.
    - Draw wiring and control diagram or get help from contractors.
    - Try to implement it internally or get external contractors.
    - Wiring and accessories Cost Range: JD 5 – 50 / unit.
    - Installation Cost Range : JD 15 – 50 / Unit.

**5. Investment details:**

- Equipment:
  - Occupancy Detector : JD 75.
- Wiring & Accessories:
  - Wiring & PVC Pipes : JD 25.
- Installation:
  - Electrical Technician : JD 25.

**Total Initial Implementation Cost : JD 125.**

**6. Payback Period**

- Simple Payback Period = Initial Investment / Annual Savings (Years)  
= 12 \* investment / Annual Savings (Months)
- Complex Payback Period
  - For large Investments.
  - Related to Interest Rate & Savings Variations.

**Maintenance**

- Lighting Lamp has certain lifetime.
- Compare lifetimes before replacing any lamps.
- Electronic Ballasts Lifetime is Greater than Magnetic Ballasts and Also Increase Lamps Life Time.
- Reflectors life time is very long (>15 Years).
- Consider Control Measures if Payback Period is less than Three Years Since Equipment May Fail.
- Look at the Annual Savings and P/B and Decide.

## **Section IV**

### *Air Conditioning System*

## **Topics that will be covered in this session**

- ◆ Air Conditioning Equipment.
- ◆ Distribution Systems.
- ◆ Reducing Cost of Generating Cooling:
  1. Raise chilled water temperature.
  2. Reduce condenser water temperature.
  3. Reduce scale or fouling.
  4. Reducing auxiliary power consumption.
  5. Heat Recovery System.
  6. Absorption chilling.
  7. Thermal Storage.
- ◆ Reducing the amount of cooling:
  1. Optimize temperature and relative humidity.
  2. Use correct amount of outside air.
  3. Use temperature reset.

## **Tips**

- ❖ Reducing infiltration will result in energy savings.
- ❖ Put the set point of the AC not lower than 22-24 °C only.
- ❖ Always clean the filters and condensers.
- ❖ Efficient lighting system will reduce cooling load.
- ❖ Reduce solar heat gain through windows (Solar films).

# Air Conditioning System

## BACKGROUND

### A / C EQUIPMENT

#### ) Window or through the wall

- Normally used for air conditioning.
- Can be provided with electric resistance heaters for heating.
- They are usually of the “ Fan coil “ type.
- Equipped with separate fan motors driving the condenser and the evaporative fans.
- Equipped with built in thermostat.



#### 2) Split Units

- There is no chilled water system since the system operates with direct expansion.
- Manufacturers claim first cost savings of 20% and power savings up to 25% due to the elimination of the chiller and water pump.
- Most room air conditioners and split units are now given an Energy Efficiency Ratio (EER), which enables you to determine the relative efficiency of different units in terms of BTU/Watt-hr.
- Newer and more efficient units will have an EER of (10) or above.



### 3) Roof Top Unit

- Self-contained air conditioning systems designed for mounting on the exposed roof of a commercial or industrial building.
- They are most frequently of the reciprocating type and air-cooled with all components contained in a weatherproof enclosure.



### 4) Electric Driven Compressors

- Can be of the reciprocating, centrifugal or screw types.
- The reciprocating compressor consists of pistons in from 1 - 12 cylinder acting as pumps to increase the pressure of the refrigerant from the low side to the high side of the system.
- Centrifugal units are basically fans or blowers, building refrigerant pressure by forcing the gas through a funnel shaped opening at high speed.
- Screw Compressors are mainly two screws building the refrigerant pressure as the male and female high displacement rotors rotate and mesh with each other.
- Centrifugal compressors are water cooled, more quite, requires less maintenance not generally used below 50 tons capacity.



#### ) Absorption Chillers

- Operate on either steam or hot water above 250 °F with two components, the generator and the absorber, performing the same basic function as a compressor .
- The chilling effect is obtained through the interaction of two connected, closed tanks with Lithium Bromide.

## COEFFICIENT OF PERFORMANCE

- This term is used to measure the efficiency of different types of chillers.

$$\text{C.O.P} = \frac{\text{Heat Moved (Refrigeration Effect)}}{\text{Energy Required}}$$

- As a rule of thumb the following C.O.P can be used as a guide for various types of units:

- 1) Absorption Chiller : 0.50.
- 2) Electric Drive Compression : (2.40 - 5).

- C.O.P will vary significantly based upon a number of factors:

- 1) The type of refrigerant.
- 2) Motor efficiencies.
- 3) Pump efficiencies
- 4) Air cooled chillers, , generally have a lower C.O.P. than water cooled units.

## SELECTION GUIDE

The following is a rough guide for selection:

- up to 80 tons (280 kW) - Reciprocating.
- 80 - 120 tons (280-420 kW) Reciprocating or Centrifugal.
- 120 tons to 200 tons (420 - 700 kW) - Screw, Reciprocating or Centrifugal.
- 200 to 800 tons (700 - 2800 kW) - Screw or Centrifugal.
- Above 800 tons (2800 kW) – Centrifugal.

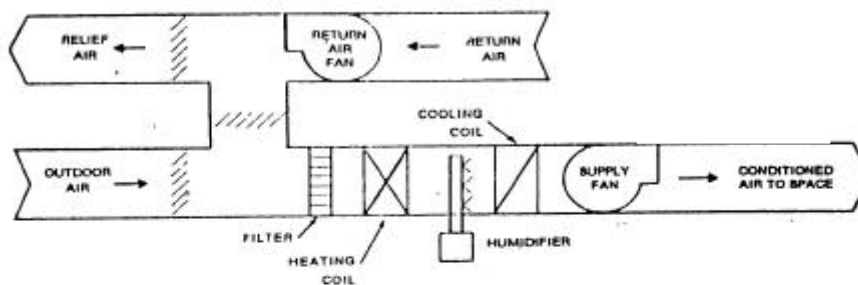
## COOLING TOWERS

- A cooling tower is a device that cools water directly by evaporation.
- It operates on the principle of adiabatic heat exchange (no heat is added to or subtracted from the system).
- Cooling is accomplished by spraying water into a tower with trays to allow for gradual passage of the hot water from top to bottom.
- Air is introduced at the bottom by fans, exhausting at the top.
- Although parabolic - or natural draft - cooling towers are available which use no mechanical devices for introducing cooling air to the tower.
- In cooling tower operations, it is assumed that for every pound of water evaporated there are 1000 BTU of heat removed. (about 550 Kcal/kg ).
- The rate of evaporation is affected by the wet bulb air temperature and the cooled water temperature.
- The difference between the two is known as the approach temperature.
- Towers are most commonly sized for a 10 F degree approach.

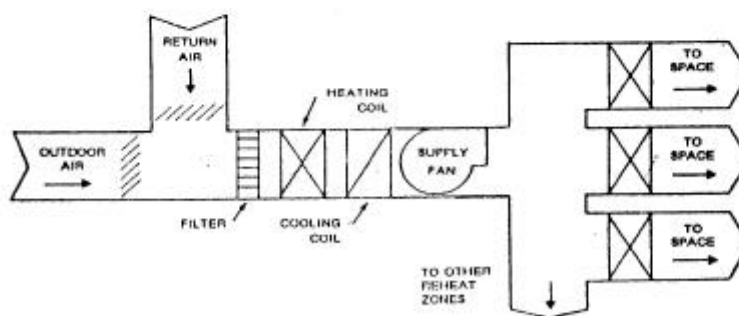
## DISTRIBUTION SYSTEMS

The distribution systems of HVAC networks is classified according to the type of network and to the number of pipes used to supply cold and hot water to the different zones, and as follows:

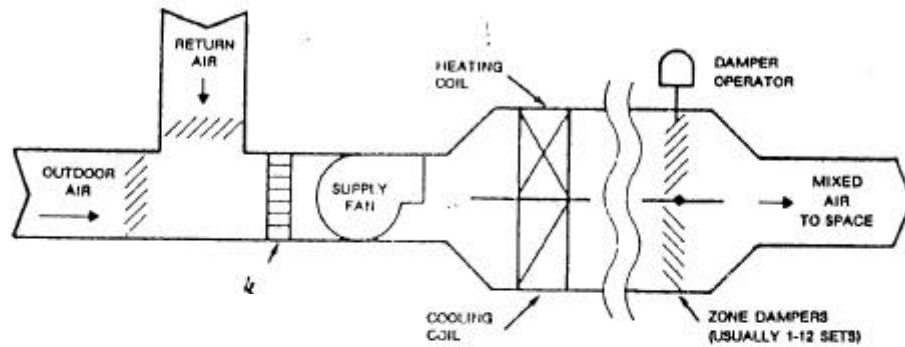
- 1) **Single Zone Systems:** These are the most basic types of system. They consist of mixing conditioning, and fan section.



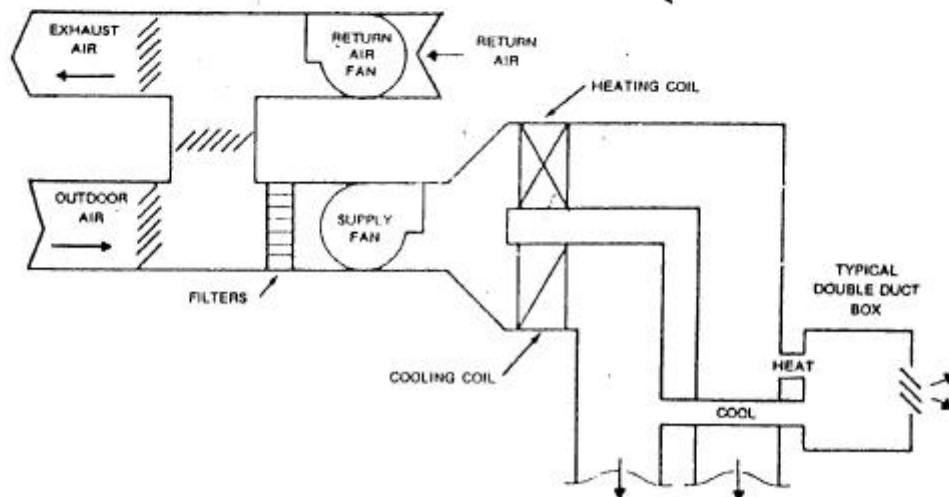
- 2) **Terminal Reheat Systems** Fixed cold temperature air is supplied to the reheat system in the terminal units as required by thermostats located in each conditioned space.



- 3) **Multi Zone Systems:** These condition all air at the central system and mix heated and cooled air to satisfy the various zone loads as sensed by zone thermostats.

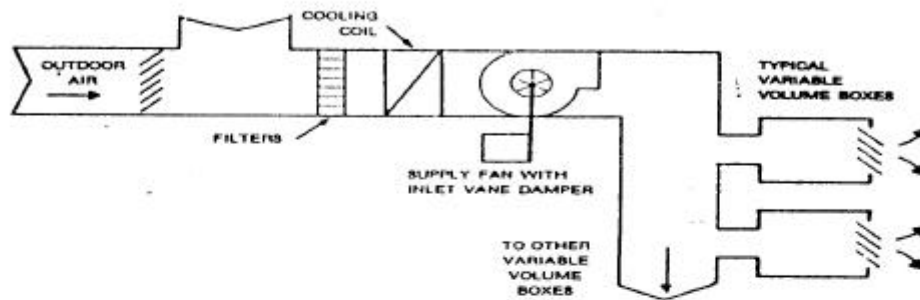


- 4) **Dual Duct Systems:** Air is ducted to the spaces and mixed in terminals boxes .

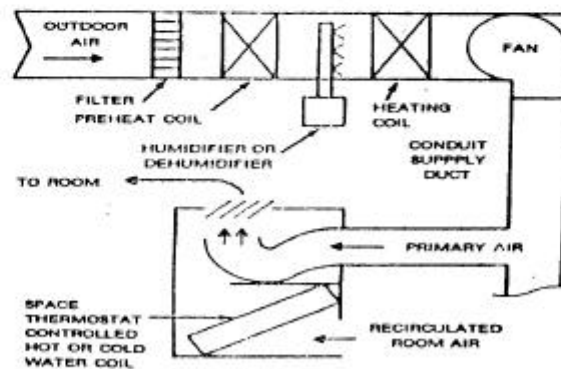


# Air Conditioning System

- 5) **Variable Air Volume Systems:** This system delivers a varying amount of air as required by the conditioned zone. Terminal sections are usually single duct variable volume boxes with or without reheat controls.

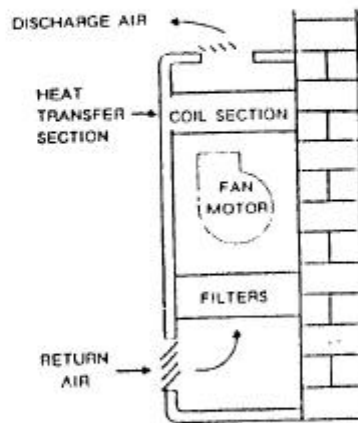


- 6) **Induction system:** Conditioned primary air is supplied to the unit where it passes through nozzles or jets and draws room air through the induction unit coil..

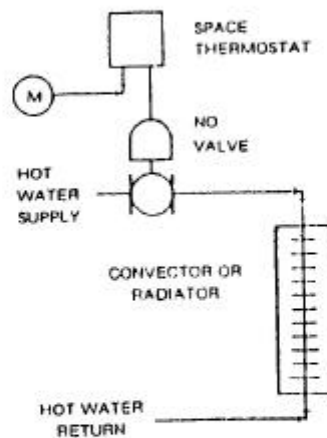


# Air Conditioning System

- 7) **Fan Coil System:** A simple cabinet with heating and/or cooling coil, filter, fan and motor. It generally uses 100% return air to condition the space.

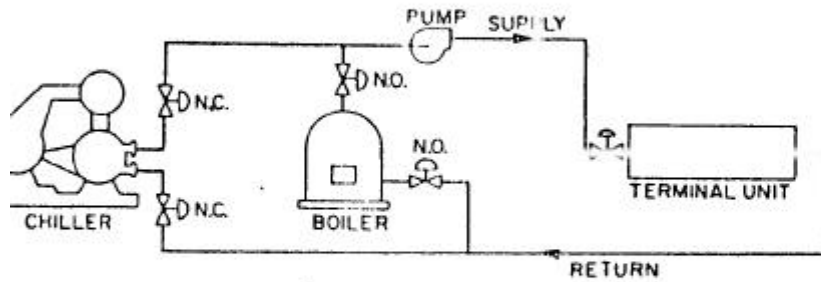


- 8) **Perimeter Radiator:** They are normally used around the perimeter of a building and under windows to compensate for heat loss through the walls.

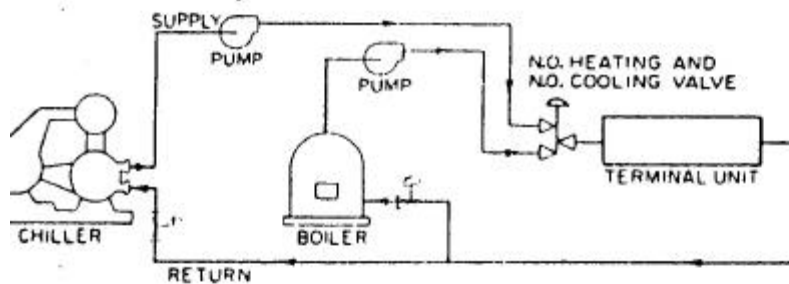


# Air Conditioning System

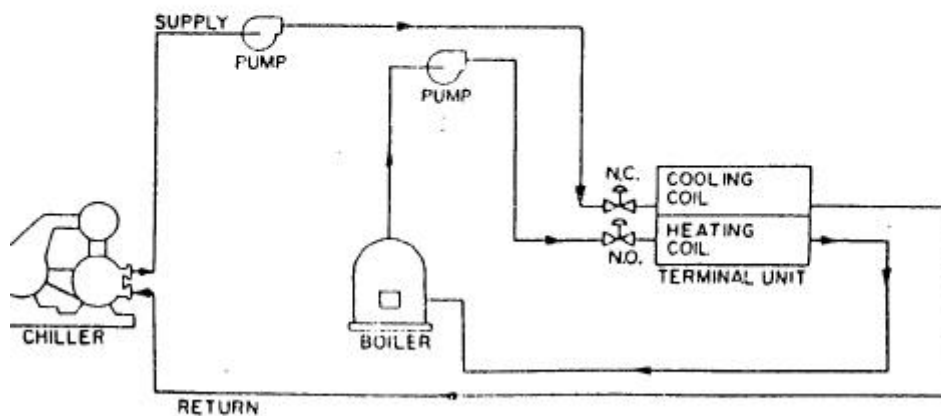
- 9) **Two Pipe System:** This system is used to transmit hot or chilled water through the same piping for heating and cooling.



- 10) **Three Pipe System:** In this system there is one pipe for chilled water, one for hot water, and the third serves as a common return.



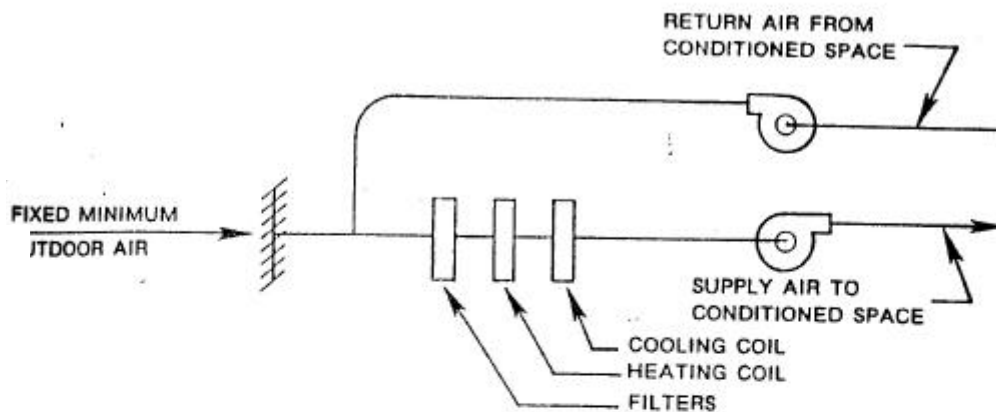
- 11) **Four Pipe System :** One pipe is used for hot water, another for cold water and two pipes for their return.



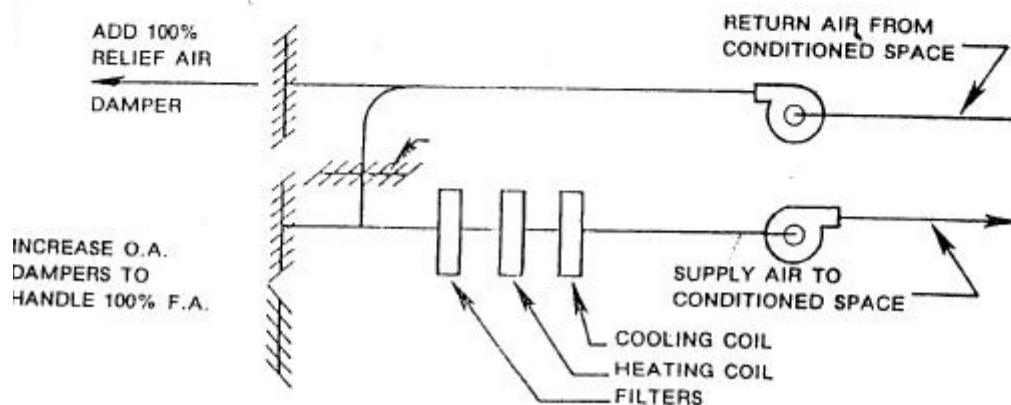
# Air Conditioning System

- 12) **Economy Cycles:** They are used to allow you to take advantage of the maximum possible use of outdoor air when that temperature is lower than the normally circulated inside air in the cooling cycle.

### Typical A.C. System Without Economy Cycle



### Typical A.C. System with economy cycle



# Air Conditioning System

# Energy Saving In HVAC System

## METHODS TO REDUCE ELECTRICITY COSTS FOR HVAC

- Savings can be divided into two general areas:
  - A) Reducing the cost of generating heating and cooling.
  - B) Reducing the amount of heating and cooling required.

### **A. REDUCING COSTS OF GENERATING COOLING.**

The basic principle to be applied in reducing the cost of refrigeration is:

- 1) Operate the temperature of the conditioned space as high as possible.
- 2) Lower the temperature in the heat rejection process to minimum.

#### **POTENTIAL NO. 1: Raise Chilled Water Temperature.**

- The energy input required for any liquid chiller increases as the temperature lift between the evaporator and the condenser increases.
- Raising the chilled water temperature will cause a corresponding increase in the evaporator temperature and thus decrease the required temperature lift.
- The Ch.W.T leaving the chillers usually remains constant or even decreases as the cooling load decreases.
- Since the cooling load is less than the designed for about 95 % of the time and since the design Ch.W.T is chosen to satisfy Max. demand, reduced demand can be met with water that is not quite so cool.
- The following table is used to find out the percentage of savings from increasing the chilled water temperature.

**Chilled Water Temperature Increase, °F**

Machine	1	2	3	4	5	6	8	10
Absorption	0.8%	1.6%	2.4%	3.2%	4%	4.9%	6.5%	8.1%
Centrifugal	1.6%	3.2%	4.8%	6.4%	8%	9.6%	12.8%	16%

**Example:**

An office building has two 150 Ton chillers, electricity tariff is 0.063 JD/kWh, cooling season is 10 hrs/day, 25 day/month, 5 month/year, average loading 50%.

- What are the JD per year attained from increasing chilled water temp. by 3 °F?

1. From chiller catalogue "Petra" at 95 °F ambient.

2. At 45 °F  $\Rightarrow$  kW/TR = 1.009 (for comp only).

3. At 48°F  $\Rightarrow$  kW/TR = 0.982 (for comp. Only).

$$\begin{aligned}
 4. \text{ Saving} &= 2 \times 150 \times 50\% \times (1.009 - 0.982) \times 10 \times 25 \times 5. \\
 &= 5062.5 \text{ kWh} \\
 &= 5062.5 \times 0.063 \\
 &= 318.94 \text{ JD/yr}
 \end{aligned}$$

**POTENTIAL NO. 2: Reduce Condenser Water Temperature.**

- The effect of reducing condenser water temp. is very similar to that of raising the Ch.W.T , namely reducing the temp. lift that must be supplied by the Compressor.
- Some water cooled systems have cooling tower bypass valves that maintain the temp. of the cooling water entering the condenser while outside temp. drop.

**Condensor Temperature Reduction, °F**

Machine	1	2	3	4	5	6	8	10
Absorption	0.5%	1.1%	1.6%	2.1%	2.6%	3.2%	4.2	5.3%
Centrifugal	1.1%	2.2%	3.3%	4.4%	5.5%	3.6%	8.8%	11%

**POTENTIAL NO. 3: Reducing Scale or Fouling**

- The heat transfer surfaces in chillers tend to collect various mineral and sludge deposits from the water that is circulated through them.
- Any build-up insulates the tubes in the heat exchanger causing a decrease in heat exchanger efficiency.
- Thus, requiring a large temp. difference between the water and the refrigerant.
- If fouling occurs in the evaporator tubes, the effect is equivalent to lowering the Ch.W.T in clean tubes.
- In the condenser, fouling is equivalent to raising the condenser water temp.in clean tubes.

**POTENTIAL NO. 4: Reducing Auxiliary Power Consumption**

- The total energy cost of producing chilled water is not limited to the cost operating the chiller itself.
- Condenser or cooling tower fans, condenser water circulating pumps, and chilled water circulating pumps must also be included.
- In fact, in centrifugal chilling plants, the auxiliary equipment often consumes 25 % or more .

**POTENTIAL 5: Heat Recovery System**

- Exhaust air temperature from any air-conditioned space always less than the ambient fresh air temperature.
- By Installing heat wheel between the relatively low temp exhaust air and the relatively high temp. fresh air will reduce the cooling load of this fresh air.

**POTENTIAL NO. 6: Use Absorption Chilling to Shave Peak**

- In installations where the electricity demand curve is dominated by the demand for chilled water, absorption chillers can be used to reduce the overall electricity demand.
- Although absorption chilling is rarely competitive on an annual basis, use of absorption chilling for short periods of time during peak load can reduce the total energy bill.

**POTENTIAL NO. 7: Thermal Storage**

- The storage of ice for later use is an increasingly attractive option.
- Because of utility demand charges, it is more economical to provide the cooling source during non air-conditioning periods and tap it when air conditioning is needed, especially peak period.

## **B. REDUCING THE AMOUNT OF COOLING OR HEATING REQUIRED.**

### **POTENTIAL NO. 1: Optimize Temp. and Relative Humidity**

- There is a "comfort zone" which is acceptable to the residents of that zone and/or to the process taking place in the zone.
- ASHRAE Standard 55-88, 1981, describes the comfort zone for people-occupied spaces for cooling and heating (Refer to the appendix).
- For example, in the summer operating at a zone humidity level of 30% R.H when 65 % would suffice is obviously much more energy expensive.
- Electrical costs can be reduced by 25 % by simply optimizing zone conditions.
- Set room sensor cooling temp. to 23 °C (74 °F) or higher where possible.

			Recommended Inside Design Conditions			
			Summer			
			Deluxe		Commercial	
			D.B °F	RH %	D.B °F	RH %
Apt, hotel, office, school, hosp			74-76	45-50	77-79	45-50
Shops, barber, supermarket			76-78	45-50	78-80	45-50
Auditorium, resturant			76-78	50-55	78-80	50-60

### **POTENTIAL NO. 2: Use Correct Amount Of Outside Air**

- Ventilation requirements ( inside activities ) will dedicate the minimum amount of makeup air .
- In certain cases it is more economical to use more than this minimum level.
- If cooling is required and the outside air temperature and humidity is less than the return air temperature and humidity, it is cheaper to use 100 percent outside air.
- There are two automatic control methods for accomplishing this:

#### **1. Economy Cycle**

The temp of the outside air is taken and then used to determine the optimum split without reference to the difference in Relative Humidity (latent heat load) between the two streams.

#### **2. Enthalpy Control**

Both the temp and Relative Humidity of the outside air is measured to optimize the return air/makeup split.

**Example:**

Suppose we have average 78 °F return air at 50% R.H and average 92 °F outside air at 42% R.H. The system flows 10000 CFM of air. In the example we will consider a single zone system in a cooling mode.

System operation: 10 hr/day, 25 day/month, 5months/yr

**Effect of Percent Outside Air on Cooling Coil Load**

<b>% Outside Air</b>	<b>Room Sensible Load (Ton)</b>	<b>Room Latent Load (Ton)</b>	<b>Room Total Load (Ton)</b>	<b>Cooling Coil Load (Ton)</b>
35	21.1	4.4	25.5	35.6
20	21.1	4.4	25.5	31.1

$$\text{Sensible Heat} = \text{CFM}_{\text{sa}} * 1.08 * (T_{\text{rm}} - T_{\text{sa}})$$

$$\text{Latent Heat} = \text{CFM}_{\text{sa}} * 0.68 * (W_{\text{rm}} - W_{\text{sa}})$$

$$\text{Total Heat} = \text{CFM}_{\text{sa}} * 4.45 * (h_{\text{rm}} - h_{\text{sa}})$$

- The reduction in cooling coil load is from 35.6 tons to 31.1 tons, a decrease of 12.6 percent.

$$\begin{aligned} \text{Reduced Load} &= 35.6 - 31.1 \\ &= 5.5 \text{ TR} \\ &= (5.5 \text{ TR} * 12000 \text{ BTU/TR}) / 3412 \text{ BTU/kWh} \\ &= 19.34 \text{ kWh (Cooling)} \end{aligned}$$

$$\text{C.O.P} = 3$$

$$\begin{aligned} \text{Power Consumed} &= 19.34 / 3 \\ &= 6.45 \text{ kWh (Electricity)} \end{aligned}$$

$$\begin{aligned} \text{Power Cost} &= 6.45 * 0.063 \text{ JD/kWh} \\ &= 0.406 \text{ JD/hr} \\ &= 0.406 * 10 * 25 * 5 \\ &= 507.5 \text{ JD/yr.} \end{aligned}$$

**POTENTIAL NO. 3: Use Temperature Reset**

- In many reheat systems the chilled water coil is operated at a fixed leaving temperature.
- Many times the temp. for air leaving the chilled water coil is chosen to be lower than any air required at the various zones.
- Therefore, the reheat coils must all operate. The overall affect is to cool the air and then reheat it back to the same state or higher temp as required.
- If this temperature is too low, more heat will be required.
- Temperature reset refers to automatically changing the temperature leaving the cooling coil for a reheat system and the mixed air temperature for the other systems so that a minimum of heat is required.

**Example**

In hospital, a 9000 CFM multi-zone AHU, mixed air temp 81 °F and 48% RH cooled down to 55 °F.

Zone # 1 : 3000 CFM at 65 °F

Zone # 2 : 3000 CFM at 80 °F

Zone # 3 : 3000 CFM at 95 °F

Air Temp. Leaving Chill Water Coil °F	Chill Water Coil, Load BTU/Hr	Reheat Coil Load For Zone 1 BTU/Hr	Reheat Coil Load for Zone 2 BTU/Hr	Reheat Coil Load for Zone 3 BTU/Hr	Total Reheat Load BTU/Hr
55	379000	33000	82500	132000	247500
65 *	180000	0	49500	99000	148500

By using temp reset ( 65 °F instead of 55 °F ) :

- The cooling requirements are lowered by 199000 BTU/hr (52 % ) .
- The heating requirements are lowered by 99000 BTU/hr ( 40 % ) .

Based on a cost of JD 4.1 / 1000000 BTU for heat , and electrical cost of 0.063 JD/kWh and machine C.O.P of 3.

$$\begin{aligned}\text{Savings in Reheat} &= 99000 \text{ BTU/hr} * \text{JD } 4.1 / 1000000 \text{ BTU} \\ &= 0.406 \text{ JD/hr.}\end{aligned}$$

$$\begin{aligned}\text{Savings in Cooling} &= (199000 \text{ BTU/hr} * 0.063 \text{ JD/kWh}) / \{(3412 \text{ BTU /kW-hr} * 3)\} \\ &= 1.225 \text{ JD/hr.}\end{aligned}$$

$$\begin{aligned}\text{Total Saving} &= 0.406 + 1.225 \\ &= 1.631 \text{ JD/hr}\end{aligned}$$

**Other Potentials**

- Insulation (pipes, ducts etc)
- Reducing infiltration ( doors, windows )
- Reducing Solar heat gain through windows (solar films, curtains etc)
- Installing air curtains on main entrance doors and on cold stores.
- Efficient lighting system will reduced cooling load.
- Controlling exhaust fans operation during night period
- Using oil additives.
- Cleaning condensers.
- Checking control system accuracy (timers, thermostats, etc).

# Air Conditioning System

## **Section VI**

### *Electric Motors System*

## **Topics that will be covered in this session**

- ◆ Types of motors.
- ◆ Motor losses.
- ◆ Motor characteristics.
- ◆ Measurements of Motor Performance.
- ◆ Energy Saving Measures:
  1. Automatic Control of Motor Operation.
  2. Matching Motor to load.
  3. High Efficiency Motors.
  4. Variable Speed Drives.

## **Tips**

- ❖ Induction motors represent 90% of existing motors.
- ❖ Total losses in motors are about 10%-20%.
- ❖ Put a maintenance schedule for all the motors.
- ❖ Rewinding of the motor will affect its performance.
- ❖ Don't forget to include any accessories or electric panel and wiring required in the investment.

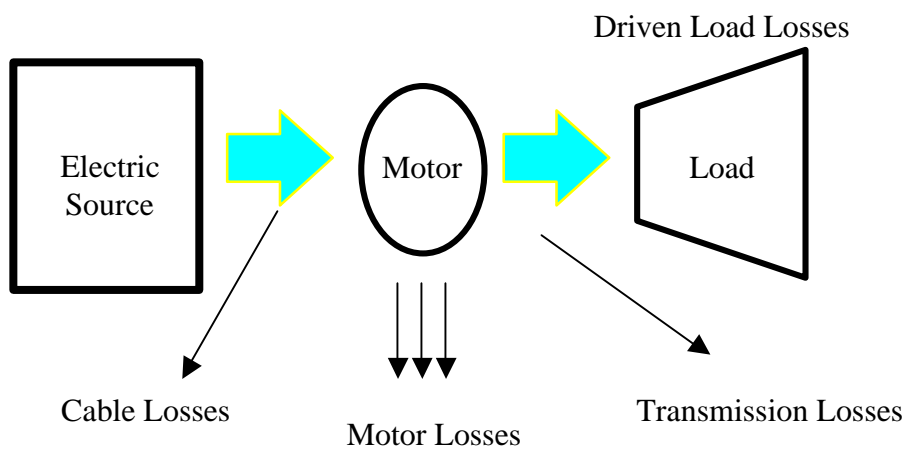
# Motors Background

## Types of Motors:

1. Squirrel Cage Induction Motors: About 90 % of Existing Motors.
2. Synchronous Motors.
3. Slip-Ring Motors.
4. DC Motors.

## Motor Performance:

### Typical Motor Setup:

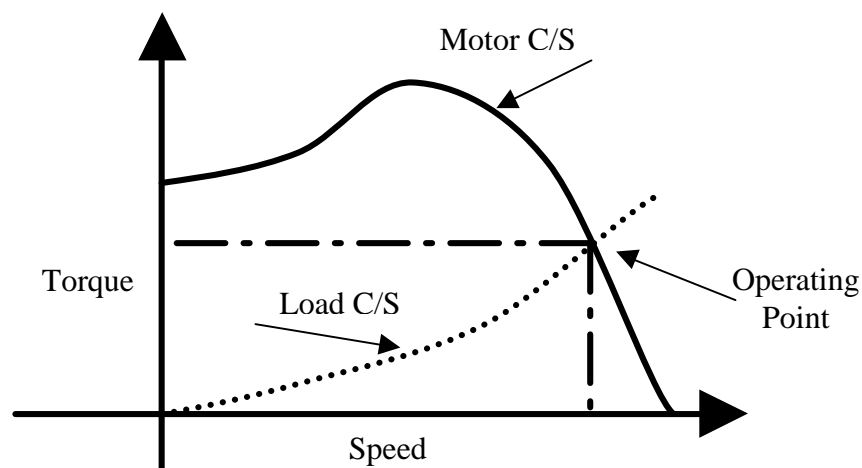


- **Output Power = Torque x Speed / 9550**

- Power : in kW
- Torque : in N.M
- Speed : in RPM

- **Torque / Speed C/S's:**

- System C/S Curve:
- Motor C/S Curve:



**Input Power:**

- Single Phase                    =  $V \times I \times \text{P.F.}$
- Three Phase                    =  $\sqrt{3} \times V \times I \times \text{P.F.}$

Input Power                                = Output Power + Losses

Motor Efficiency                        =  $P_{\text{out}} / P_{\text{in}}$

**Motor Losses****A) Magnetic (Core) Losses:**

1. Hysteresis Losses : Energy required to magnetize the core material.
  2. Eddy Current Losses: Due to current passing through the core material.
- Voltage Related
  - Constant Irrespective of Motor Load
  - Fixed Losses 15 - 20 % of Total Losses.

**B) Copper Losses ( $I^2R$  Losses):**

- $I^2R$  Losses in Rotor & Stator.
- Proportional to the Load Current.
- Stator Losses: 40 - 45 % of Total Loss.
- Rotor Losses: 20 - 25 % of Total Loss.

**C) Friction (Mechanical Losses):** Function of the motor speed.

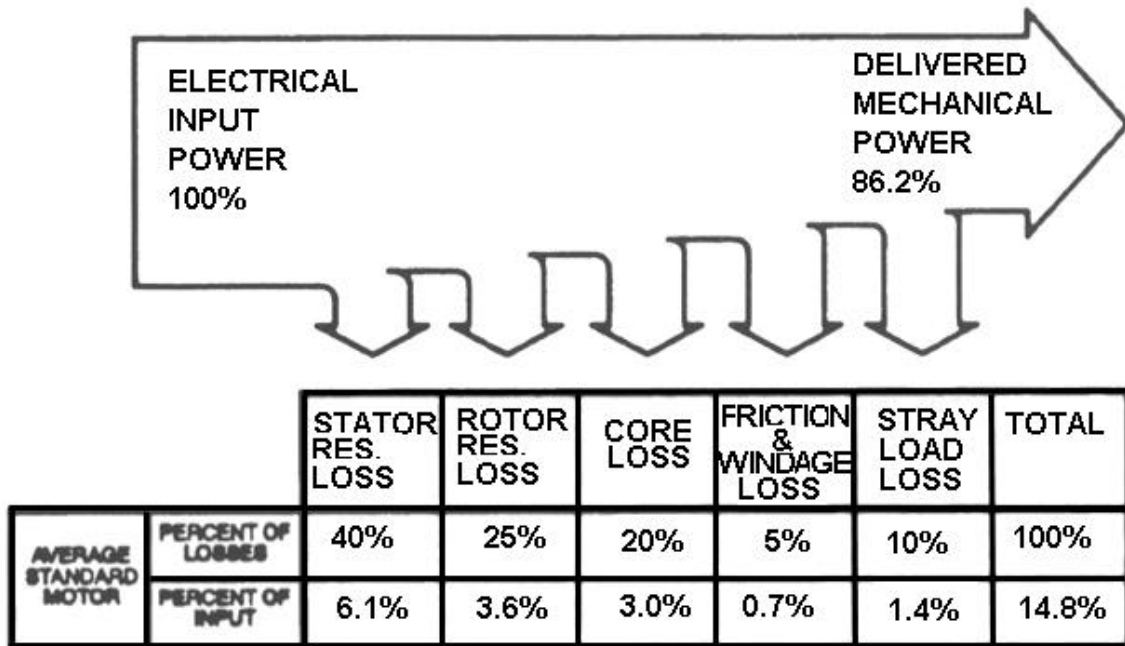
- Windage Losses.
- Bearing Losses.
- Brush Friction Losses.
- Fixed Losses: 5 - 10 % of Total Losses.

**D) Stray Losses:**

- Result of Leakage Flux Induced by the Load Currents.
- Difficult to be Measured or Calculated.
- Generally: Proportional to ( $I_{\text{rotor}}$ ).
- 10 - 15 % of Total Motor Losses.

**Example:** An example illustrating different kinds of motor losses.

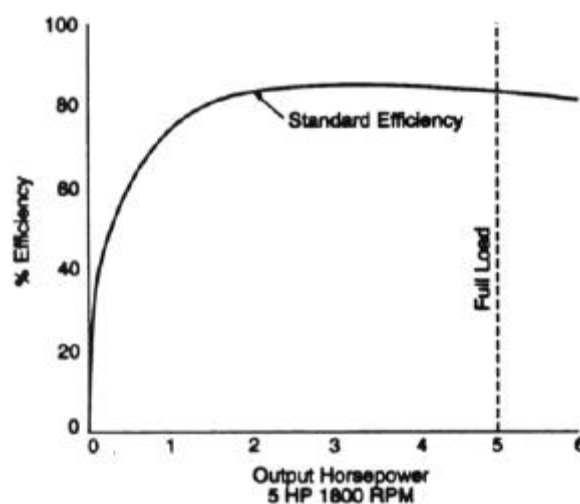
### 5 HP, 4 POLE, 3 PHASE MOTOR TYPICAL ENERGY FLOW



#### Motor Characteristics:

Manufacturers Usually Supply Motor C/S's as Curves or Tables.

- Motor Efficiency (Vs) % Loading



## Measurements of Motor Performance

- Input Power:
  - Can Be Measured Using Digital P.F Meter or Power Analyzer.
- Motor Efficiency:
  - We Need to Determine Motor Loading.
  - There is Two Approaches to Determine Motor Loading then Efficiency.

## Determine Motor Efficiency

### A. Input Power Method:

1. Input Power Measurement.
2. Manufacturer:
  - Efficiency vs. Output Power.
3. Draw Efficiency vs. Input Power.
  - By Dividing P.out / Efficiency.
4. Using New Curve Determine Efficiency.

### B. Speed Measurement Method:

1. Using a Tachometer: Measure Motor Speed (RPM).
2. Using Speed vs Motor Load % Curve: Determine the Loading of the Motor.
3. Using Efficiency vs Motor Loading %: Determine Motor Efficiency.

### Note: Frequently, Manufacturer Data are Not Available

- Use General Curves Available or Make Approximations.

$$\% \text{ Load} = \frac{\text{No load rpm} - \text{actual rpm}}{\text{No load rpm} - \text{full load rpm}} \times 100$$

Where,

No load rpm = Sync. Speed =  $120 \times f / P$ .

Full load rpm = Name Plate rpm.

**P out = % Loading \* P rated**

**Eff. = P out / P in**

## Factors Affecting Motor Performance

1. Maintenance.
2. Rewinding.
3. Power Supply Quality.
  - Voltage Variations :  $\pm 6 \%$
  - Frequency Variations :  $\pm 3 \%$
4. Age.

# Energy Saving Measure

## Motors - Check List

Before starting with the energy saving measures, the following data should be obtained, in order to determine the suitable motor for any measure. Most of the data required could be obtained from the name plate of the motor, or could be found in the catalogues:

- Motor Nameplate Details (V, A, PF, kW, RPM, Frame..).
- Motor Type (AC, DC, ..).
- Motor Application (Pump, Fan, Conveyer, etc...).
- Motor Running Duration.
- Motor Control (Manual, Automatic and how).
- Existing Starter (DOL/ Star Delta).
- Age of the Motor.
- Motor Rewinding.
- Motor Actual Measurements (V, Amp, PF).
- Power Factor Correction.
- Motor Running Temperature.

## Main Energy saving measures:

In this section we will explain the following energy saving measures:

1. Automatic Control Of Motor Operation.
2. Matching Motor to Load or Replacing Oversized Motors.
3. Install High Efficiency Motors.
4. Control Motor Speed (Variable Frequency Drive).

### 1. Automatic Control Of Motor Operation:

Sometimes motors are left operational when there is no need for that, so it is suggested to control these motors and turning it off when there is no need for it.

- **Examples:**
  - Air Compressors.
  - Exhaust Fans.
  - Air Handling Units.
  - Ventilation Units.

**Turning off those motors will save a lot of Energy, while no or low investment is required, this could be done by:**

- A. Programmable Timers.
- B. Temperature Controllers.
- C. Level Switches.
- D. Pressure Controllers.

## Savings Calculations:

- Calculate Existing Motor Consumption:

$$\text{Annual Savings in kWh} = \text{Motor kW} \times (H_1 - H_2)$$

Where:

- $H_1$  : Existing Motor Operating Hours.
- $H_2$  : New Proposed Motor Operating Hours.
- Motor kW from measurements or 70% of Rated kW.

$$\text{Annual Savings in JD} = \text{Savings (kWh)} \times \text{Tariff (JD/kWh)}$$

## 2. Matching Motor to Load:

Motors are usually oversized for the following reasons:

- Safety Factors.
- Over Estimated Loads.
- Wrong Calculations.
- Voltage Drop.

### Identifying the Measure

To determine if the motor is oversized or not , some measurements should be taken:

1. Electrical Measurements:
  - Power (kW).
  - Power Factor.
2. Speed Measurements (RPM).

Using the previous mentioned equation, calculate the Loading Ratio:

$$\% \text{ Load} = \frac{\text{No load rpm} - \text{actual rpm}}{\text{No load rpm} - \text{full load rpm}} \times 100$$

**If Motor Loading Ratio < 50 %, then**

- Efficiency Will be very Low.

⇒ Calculate for Replacing it.

### Calculations

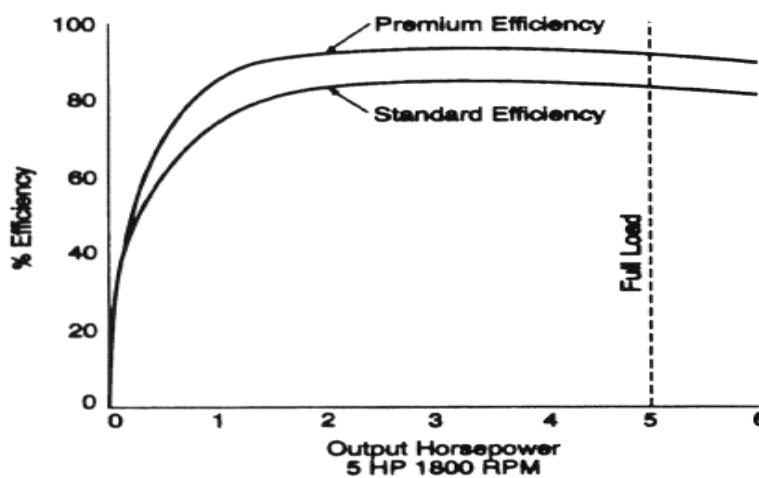
- A. Existing Motor Load & Consumption.
- B. Proposed Motor Load & Consumption.
- C. Savings = Difference.

### 3. High Efficiency Motors:

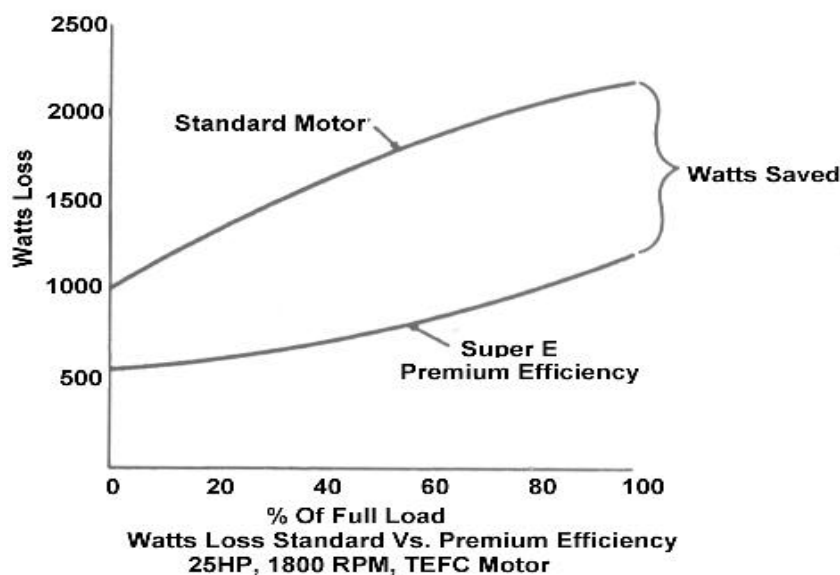
Main characteristics of High Efficiency Motors:

- 3 -5 % More Efficient than standard motors.
- Better Efficiency C/S's.
- Similar or Higher Power Factor.
- Lower Temperature and Noise.
- Less Affected by Supply Fluctuations.

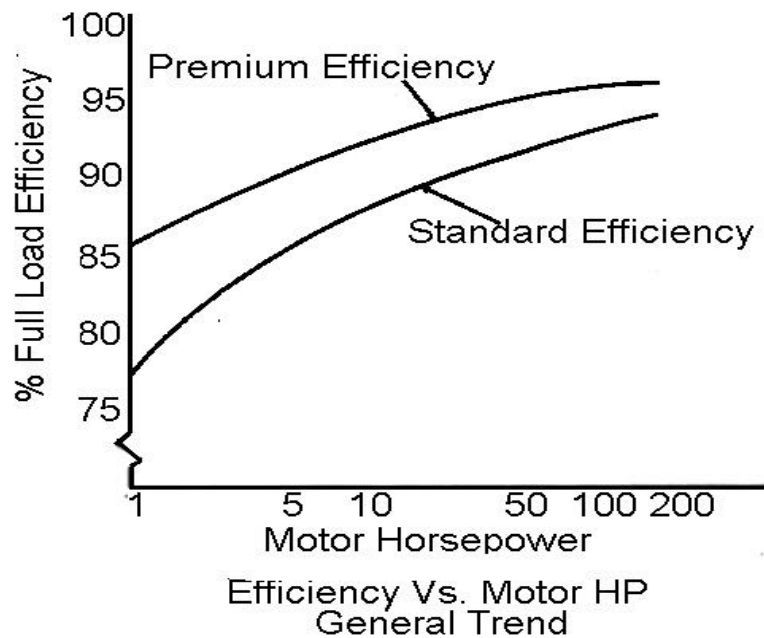
**More Efficient:** The following figure shows the difference in efficiency between the Standard motor and the high efficiency one.



**Motor Losses:** The following figure shows that the high efficiency motor has less losses than the standard motor.



**Efficiency (vs.) Horsepower:** This figure shows that as the Horse power increases the Efficiency of the standard motor and the high Efficiency Motor become close to each other.



### Energy Saving

$$\% \text{ Of Savings} = 1 - \frac{\text{Existing Motor Efficiency}}{\text{Proposed Motor Efficiency}}$$

#### Example:

Existing Motor Efficiency = 88%.

Proposed Motor Efficiency = 93%.

$$\% \text{ of Savings} = 1 - (0.88 / 0.93)$$

$$= 5.4 \%$$

**Example:****Case Description:**

An electrical motor is found to be operating **4992** hours per year. Electrical measurement showed that the power input to the motor was **25** kW, while the nameplate showed that the rated values were :

$$(kW = 22.5, V_r = 400, I_r = 45A, P.F_r = 0.85)$$

**Savings Calculations:**

$$\begin{aligned} \text{Load Factor} &= \frac{\text{Actual Power Input}}{\text{Rated Power Input}} \\ &= 25 / (1.732 * 400 * 45 * 0.85) \\ &= 25 / 26.5 \end{aligned}$$

$$\text{Load Factor} = 0.94$$

$$\begin{aligned} \text{Motor Efficiency} &= P_{out} / P_{in} \\ &= 0.94 \times 22.5 / 25 \\ &= 84.6\% \end{aligned}$$

Which means high efficiency value and this motor cannot be replaced with smaller normal efficiency motor. However, replacing this motor with a 22.5 kW high efficiency motor with 92% efficiency then some savings can be achieved.

$$\begin{aligned} \% \text{ Of Savings} &= 1 - \frac{\text{Existing Motor Efficiency}}{\text{Proposed Motor Efficiency}} \\ &= 1 - (0.846 / 0.92) \\ &= 8.0 \% \text{ of Existing Input Power.} \\ &= 8.0 \% * 25 \end{aligned}$$

$$\text{Savings} = 2 \text{ kW}$$

$$\text{Annual saving in energy cost} = 2 \text{ kW} * 4992 \text{ hr/yr} * 0.063 \text{ JD/kWh}$$

$$\begin{aligned} &= 629 \text{ JD / year} \\ \text{New Motor Cost} &= 1250 \text{ JD} \end{aligned}$$

$$\begin{aligned} \text{P/B Period} &= 1250 / 629 \\ &= 2.0 \text{ Years} \end{aligned}$$

**New Motor Specifications**

- Sufficient Size for Existing Max. Load.
- Same or Suitable Frame to fit in place of old motor.
- Same Speed.
- Same Voltage System.
- Same or Suitable C/S's.
- Same or Better Specifications.

**4. Variable Speed Drives :****Introduction**

- Variable Speed Drives (VSD) Control the Speed of the Motor to Match the Variable Load.
- Power Consumptiona (Speed)<sup>3</sup>.
- Small Reduction in Speed Will Cause Significant Reduction in Power Consumption.
- Very Big Potential But Carefully.

**Examples:** The following shows the percentage of savings that could be achieved when Reducing the speed of the motor.

<u>Speed Reduction %</u>	<u>Power Savings %</u>
5 %	14.3 %
10 %	27.1 %
20 %	48.8 %
30 %	57.8 %
50 %	87.5 %

**Features of AC Variable Frequency Drives****Standard Protection Features:**

- Over / Under Voltage.
- Soft Start/Stop.
- Phase-Phase/Earth Shorts on Output.
- Overload Protection.
- Motor Phase Failure.
- Acceleration & Deceleration.
- Electronic Reversing.
- Computer Control Option.

**Typical Applications****1. Variable Torque:**

- Compressors, Fans, Centrifugal Pumps.
- $T = k \times n^2$
- $P = k \times n^3$

## 2. Constant Torque:

- Conveyors, Agitators, Crushers.
  - $P = k \times n$
- Where , n: Motor Speed.  
k: Constant.

## Requirements for VSD Control

- High Level of Variable Load: Operating at Partial Loads for Long Times.
- Long Annual Operating Hours.
- Possibility of Speed Variation.

## Example Cases

- Pumping Applications.
- Air Handling Units.
- Under Loaded Compressors with Low Duty Cycles.
- Fans & Ventilation Systems.

## Non Suitable Applications

- Fully Loaded or Highly Loaded Motors.
- Motors that can not Tolerate RPM Decreases.
- Motors Subjected to Frequent Start/Stop Operations (e.g. Cranes).
- Motors that Handle Heavy Loads at Starting Times.
- Synchronous Motors.
- DC Motors.
- Underwater Motors.

## VFD Control

VFD can control motor speed and load in three ways:

1. Manual: from the VFD Control Panel.
2. Remote: from external control signal (temp, level, ..).
3. Time Schedule.

## Calculations

### 1. Calculate Existing Motor Consumption.

- Motor kW x Annual Operating Hours.

### 2. Determine Average New Speed: % (X)

- Savings % =  $1 - (X)^3$

**3. Use Safety Factor 0.8 – 0.95 depending on the accuracy of your calculations:**

- VFD efficiency: 95 – 98%
- Accuracy of measurements or estimation
- Speed reduction estimation

**Example:** Using Variable Frequency Drive on Heating Ventilation Fan.

**1. Computation Parameters:**

- Motor Measured Load = 11.19 kW
- Existing Operating Time = 24 Hrs/Day
- Operating Days/Month = 30.4
- Operating Months / Year = 12
- Estimated Percentage Of Savings = 53 %

The Fan was operating 24 hours at full speed. It is suggested to reduce the speed at certain periods according to the following time schedule.

Time	Hours	Speed %	Saved kW	New kW	KWh
7:00 - 14:30	7.5	90%	3.032	8.16	61.2
14:30 – 15:30	1	60%	8.773	2.42	2.4
15:30 – 19:00	3.5	80%	5.461	5.73	20.1
19:00- 20:00	1	50%	9.791	1.40	1.4
20:00 – 23:00	3	80%	5.461	5.73	17.2
23:00 – 12:00	1	50%	9.791	1.40	1.4
12:00 – 4:00	4	70%	7.352	3.84	15.4
4:00 – 7:00	3	60%	8.773	2.42	7.3
Total	24				126.2

Existing Consumption = 268.6 kWh/Day.

Average % of Savings = 53.0%.

## 2. Annual Energy Savings

**Existing Electrical Consumption** = Electrical Load(kW)\*Operating Hours/Year  
 = 11.19 kW \* 24 Hr /Day \* 30.42 D/M\* 12 M/Y  
 = 98035 kWh/Year

**Existing Energy Cost** = Electrical Consumption \* Electrical Tariff  
 = 98035 kWh \* 0.063 JD / kWh  
 = 6176 JD / Year

**Saving In Electrical Consumption** = Estimated Saving % \* Existing Electrical Cons.  
 = 53% \* 98035 kWh  
 = 51959 kWh

## 3. Annual Monetary Savings

**Savings In Energy Cost** = Savings In Electrical Consumption \* Electrical Tariff  
 = 51959 kWh\* 0.063 JD /kWh

**Annual Savings** = 3273 JD / Year

## 4. Investment Details

### **Equipment:**

VFD 15 kW	: JD 1500
Time Control Unit	: JD 300
Electrical Panel and Protection	: JD 500
Wiring & Accessories	: JD 100
Installation	: JD 100
<b>Total</b>	<b>: JD 2500</b>

**P/B Period** = 9 Months

# **Appendix B**

## *Air Conditioning Theory*

## **HEATING, VENTILATION AND AIR-CONDITIONING (HVAC) SYSTEMS**

### **INTRODUCTION**

Air Conditioning is the simultaneous control of temperature humidity, air movement and the quality of air in a space.

This section will introduce you to various types of Heating Ventilation, and Air Conditioning Systems and acquaint you with numerous options available for heating, cooling and distribution, although many of the savings to be derived from HVAC systems will be achieved by modifications, in the existing control system, a basic understanding of the HVAC system is essential in any effort to reduce energy used.

### **HEATING SYSTEMS**

Hot water heating systems can be operated by oil, gas or electricity in much the same manner as steam generating boilers. The basic difference between the two systems is in the temperature of the water-below 212 °F and operating pressure normally at the atmospheric pressure.

Electric hot water boilers operate in the same manners as electric steam boilers with the exception that boiler pressure is maintained at atmospheric pressure and the water temperature is reduced below the boiling point. Efficiencies are very high approaching 100%.

Steam and water are both used for domestic hot water and air heating distribution systems. These distributions systems are described later.

Infrared heaters operate on gas, oil or electricity and transmit heat energy directly to the occupants or building contents without appreciably heating the surrounding air. They are particularly useful in high bay buildings, semi open or outdoor areas.

Unit Heaters are mostly used for spot heating areas, they are available in propeller types or with blowers. The former are easier to maintain, but blowers are required where large heating areas require a greater distribution then is normally possible with propellers type.

Heat Pumps are system designed in such a manner that they can extract heat from outdoor air and transmit it to the inside for heating, then reverse themselves to remove heat from the inside when in cooling mode. They are generally more efficient for heating than electric resistance heaters when the outside temperature are 40 F, or higher Below that temperature a supplementary resistance heater is generally utilized.

## AIR-CONDITIONING EQUIPMENT

**Window or through the wall** units are normally used for air conditioning only, however, many are provided with electric resistance heaters for heating as well. They are usually of the Fan coil, type and are generally equipped with separate fan motors driving the condenser, and evaporative fans. Most room air conditioners are now given an Energy Efficiency Ratio (EER) which enables you to determine the relative efficiency of different units in terms of BTU/Watt-hr. Newer and more efficient units will have an EER of ten or above. For capacities 18000 BTU/hr or above, electrical requirements are 230 Volts.

As an example of the effect of EER on electrical consumption, there are two well-known air conditioners on the market, each rated at 18000 BTU capacities. Unit one has an EER of 9.7 and uses 1856 Watt each hour. Unit two has an EER of 8.8 and uses 2045 Watts each hour or 10% more electricity for the same cooling capacity.

**Electric Driven Compressors** can be of the reciprocating or centrifugal types. The reciprocating compressor consists of pistons in from 1 - 12 cylinder acting as pumps to increase the pressure of the refrigerant from the low side to the high side of the system. Centrifugal units are basically fans or blowers, building refrigerant pressure by forcing the gas through a funnel shaped opening at high speed. Centrifugal compressors are not generally used below 50 tons capacity where reciprocating units dominate the market. They are acceptable for capacities between 50 - 100 tons and particularly suited for the 100 -2000 tons range. They are generally more quiet, require less maintenance, and have less vibration than a comparable reciprocating unit, but are not suitable for use for air condensers and must be water-cooled.

**Absorption Chillers** operate on steam or hot water above 250, F with two components, the generator and the absorber,

Performing the same basic function as a compressor. The chilling effect is obtained through the interaction of two connected, closed tanks with Lithium Bromide, a salt solution in one and water in the another. The salt solution in the absorber soaks up some of the water in the evaporator, thus cooling the remaining water by evaporation. This refrigeration effect is utilized by putting a coil in the evaporator tank. Since the salt solution is continuously absorbing water vapor, part of it is pumped to a generator to maintain the proper salt concentration. Steam is used in the generator to boil off the excess water vapor. A water-cooled condenser is used to recapture the waste heat from the generator, returning to the evaporator.

**Roof Top** unit are self contained air conditioning systems designed for mounting on the exposed roof of a commercial or industrial building. They are most frequently of the reciprocating type and air-cooled with all components contained in a weatherproof enclosure.

**Screw Type Compressors** are also available from many suppliers. They function somewhat differently than the other compressor type system so are included as a separate categories.

With this type of compressors there is no chilled water system since the system operates with direct expansion. Manufacturers claim first cost savings of 20% and power savings up to 25% due to the elimination of the chiller and water pump.

The Major disadvantage of this type of system is in the limitations imposed by the need to use the refrigerant itself as a cooling medium with refrigerant run outs of 200 feet being the maximum currently possible. They are available in capacities ranging from 50 to 460 tons.

### COEFFICIENT OF PERFORMANCE

This term is used to measure the efficiency of different types of chillers. It is calculated as follows:

$$\text{C. O. P} = \frac{\text{Heat Moved (or refrigeration Effect)}}{\text{Energy Required}}$$

Although each chiller will have its own rating assigned to it by the manufacturers, as a rule of thumb the following coefficients of performance can be used as a guide for various types of units:

Absorption Chiller	-	0.50
Electric Drive Compression	-	(2.40 - 5)

We should point out here that the C.O.P will vary significantly based upon a number of factors. Air cooled chillers, for example, will generally have a lower C.O.P. than water-cooled units. The type of refrigerant, motor efficiencies and pump efficiencies will have a significant effect. In each case the manufacturer should be contacted for specific data relating to that system being evaluated (Figure 1) illustrates some of these effects.

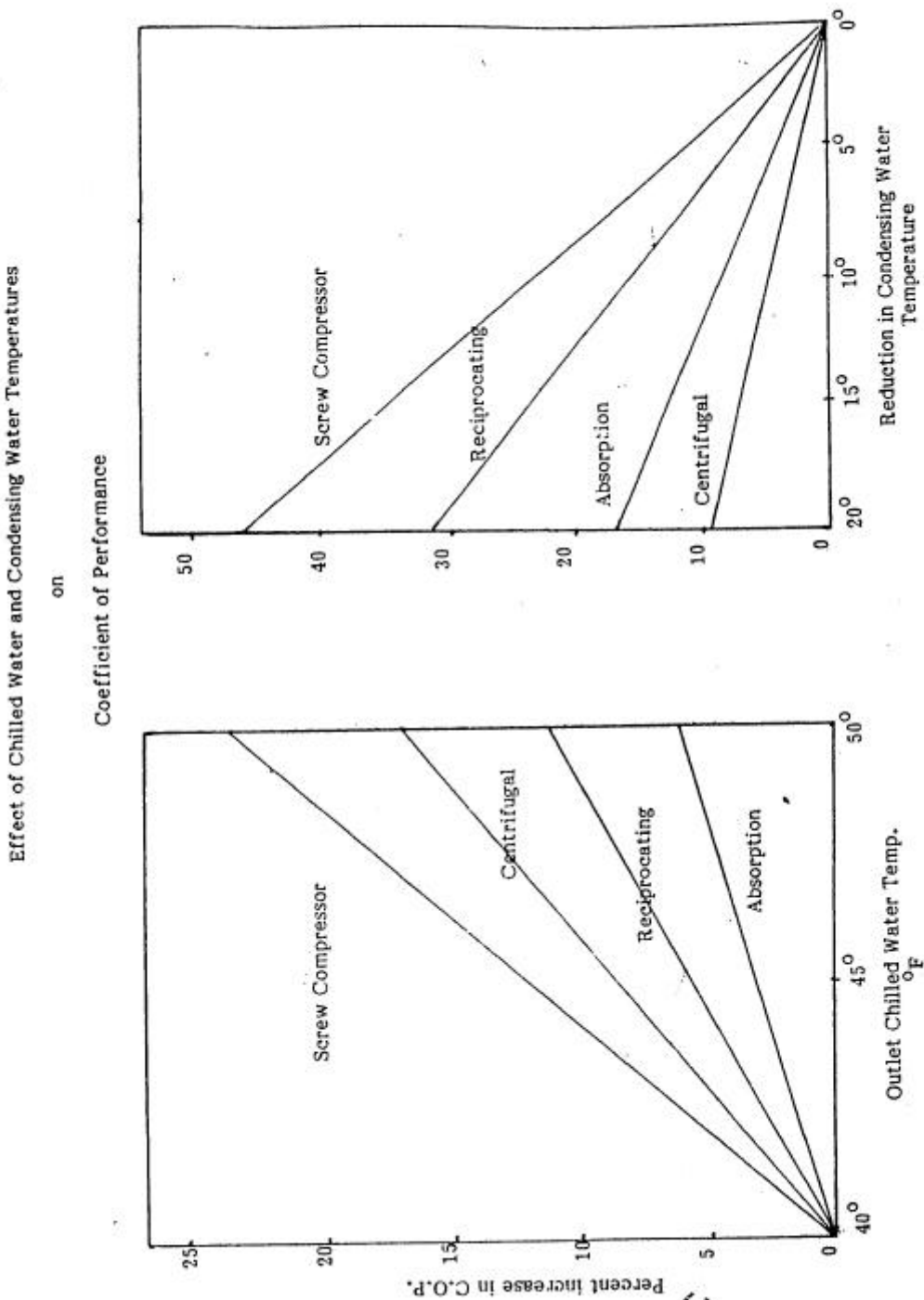


Figure ( 1 )